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ABSTRACT

Title of Thesis: The Connection between Emotion, Brain Lateralization, and Heart Rate Variability
Miranda E. Newell, Master of Science, 2005

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The central nervous system (CNS) is involved in the pathways linking emotions to autonomic nervous system (ANS) reactivity. The connection between CNS and ANS activity during emotions may explain the increased risk of cardiovascular events during highly arousing emotional states. The present study investigated 20 participants (55% female) during happiness and anger recall tasks and a stress-inducing Stroop color word task. ANS reactivity was evaluated using heart rate variability analysis, and CNS reactivity was evaluated using frontal alpha frequency band electroencephalograph (EEG). Increases in positive emotions during the happiness recall were associated with increased high frequency HRV (parasympathetic activation) as well as increased left frontal brain lateralization. Negative emotions during the Stroop task were associated with an increased low/high frequency ratio (LF/HF; sympathovagal balance). The level of emotional responsiveness was the primary predictor of HRV, whereas EEG lateralization was not related to HRV.

THE CONNECTION BETWEEN EMOTION, BRAIN LATERALIZATION, AND HEART RATE VARIABILITY

by

Miranda E. Newell

Thesis submitted to the Faculty of the

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Introduction

Positive and negative emotions have been characterized along two discrete dimensions, both of which have been hypothesized to evoke specific physiological, cognitive, and behavioral responses (Taylor, 1991). Among these physiological responses are alterations in heart rate, blood pressure, respiration, and skin conductance. Previous research has indicated that the degree to which individuals respond to a given emotional stimulus can impact their cardiovascular functioning (Carels, Blumenthal, & Sherwood, 2000). Furthermore, numerous studies have demonstrated that different emotions are associated with different patterns of autonomic nervous system (ANS) activity, as measured by heart rate variability (HRV) (Demaree, 2004; for review see Levenson, 1992). Research on the cerebral correlates of emotion has also indicated a relationship between positive emotions and relative left frontal lobe activation and a relationship between negative emotions and relative right frontal lobe activation (Canli et al., 1998). Differential brain lateralization activity may also influence ANS activation and HRV (Lane & Schwartz, 1987; Wittling, Block, Genzel, & Schweiger, 1998a; Wittling, Block, Schweiger, & Genzel, 1998b). Therefore, the purpose of the current study is to examine the effects of emotions and lateralization on ANS activity, as measured by HRV.

In the following sections, a review is provided of: (1) Conceptual and definitional considerations in emotion research; (2) Physiological reactivity to emotional laboratory tasks; (3) HRV; (4) Emotions and HRV; (5) Emotions and brain activity; (6) Emotions and brain lateralization; (7) Brain lateralization and ANS activity. This background is

followed by a description of the research methods, results, and a discussion of the present study results.

Emotion

Conceptual and definitional considerations in emotion research

Emotions are often viewed as short-lived, fluctuating changes in an individual's state of mind, and are associated with specific objects or situations (Gross, 1998). A range of physiological, biological, cognitive and behavioral factors are associated with emotional responses. In this thesis, affect and arousal are considered the two primary components that constitute an emotion (Gross, 1998; Watson & Tellegen, 1985). Emotional states are differentiated from the broader concepts of "emotional episodes" and "moods." An emotional episode includes all of the events, people, and interactions that surround an individual while he or she is experiencing a particular emotion. Mood is regarded as a more widespread, enduring, all-encompassing "emotional climate" that can influence an individual's cognitions and can pervade numerous situations (see Gross, 1998). Specific definitions of emotion vary, but many researchers employ William James' (1884) original conceptualization of emotions as "adaptive behavioral and physiological response tendencies" to significant circumstances (Gross, 1998).

Positive affect and negative affect are the two primary valence dimensions of emotion consistently analyzed throughout the emotion literature (Watson & Tellegen, 1985). As defined by Watson, Clark and Tellegen (1988), positive affect refers to the "extent to which a person feels enthusiastic, active, and alert." High positive affect can

be described as experiencing a state of increased energy, complete concentration, and/or enjoyable involvement. Low positive affect, on the other hand, includes feeling sluggish and dull. Positive affect has been related to the amount of, and satisfaction with, social activity and frequency of pleasant events experienced by an individual. In contrast to positive affect, negative affect is a "general dimension of subjective distress and unpleasurable engagement that subsumes a variety of aversive mood states" (Watson et al., 1988). High negative affect includes feelings of anger, disdain, repulsion, shame, fear, and apprehension. Calmness and serenity exemplify low negative affect. High levels of negative affect have been associated with increased levels of self-reported stress, poor coping, health complaints, and the occurrence of unpleasant events (see Watson et al., 1988).

In addition to the positive-negative affect (valence) dimensions, emotions can also vary along the arousal dimension. According to the circumplex model of emotion, the experience of an emotion does not lie on a linear continuum, but rather can be described using a circumference model (Remmington, Fabrigar, & Visser, 2000; Watson & Tellegen, 1985). Affective states, or emotions, that are similar and positively correlated are close to one another on the circle, whereas those that are dissimilar and negatively correlated are on opposite sides of the

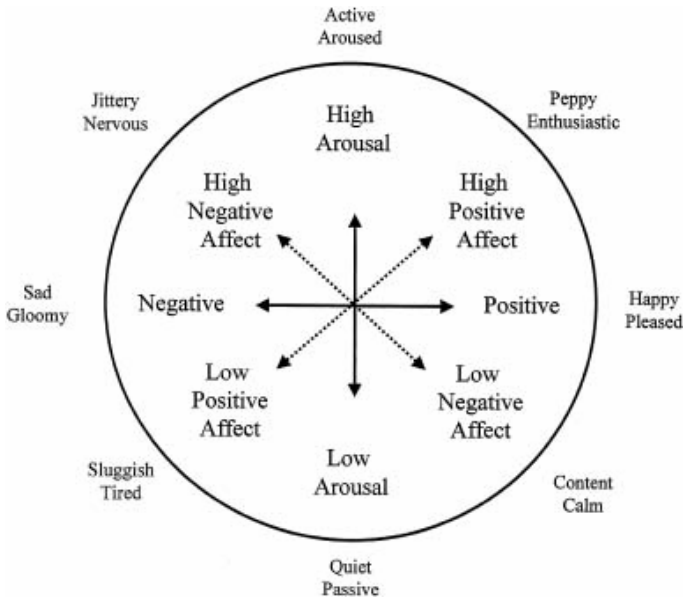


Figure 1: Circumplex Model of Emotion

circle. With this model, positive and negative affects are situated directly across from one another (at an 180^{o} angle), and are at a 90^{o} angle from the arousal dimension. High and low arousal, are also directly across with respect to one another (see Figure 1). As demonstrated in Figure 1, feelings of sadness and gloom would be negatively correlated with feelings of happiness and being pleased. Similarly, being active and aroused correlates with being jittery and nervous on the negative affect side, or peppy and enthusiastic on the positive affect side. The circumplex model is employed in the present thesis because it takes into consideration both arousal and affective valence when assessing an individual's emotional state.

The present study will assess both the affective and arousal components of emotion as they relate to autonomic nervous system reactivity (as assessed by HRV) and lateralized brain activity.

Physiological Activity during Emotional Laboratory Tasks

Positive and negative affect dimensions of emotion have been hypothesized to evoke specific physiological, biological, cognitive, and behavioral responses (Taylor, 1991). Theories concerning the causal relationship between physiological, or autonomic, activity and perceived emotional experiences were first introduced by William James in the late 1800s (James, 1994) and continued with Cannon's theory in the early 20^{th} century (see Kalat, 1998). While James proposed that the physiological reactivity to environmental stimuli occurred first, followed by the experience of an emotional sensation, Cannon theorized that the physiological arousal and the emotional experience

could co-occur independently of one another. Numerous studies have found evidence supporting both theories (for review, see Goldstein, 1968; Herd, 1972). For example, the alteration of autonomic responses, via drug application, can lead to distorted emotional experiences (Schachter & Singer, 1962). On the other hand, individuals who are completely paralyzed, with loss of sensation from internal organs, can still experience emotions (Cobos et al., 2002; Lowe & Carroll, 1985). Therefore, whether the perception of the experience of an emotion or the physiological activation associated with such an emotion occurs first is still debatable. However, emotions can be induced using presentation of emotional stimuli, such as film clips, slides, or effortful recall of an emotional experience (see Phan et al., 2002). In addition, a number of physiological responses can be measured during this emotional induction.

Physiological activity during experienced emotions includes alterations in heart rate, blood pressure, respiration, and skin conductance. Since the development of James' and Cannon's theories, there has been debate regarding the specificity of physiological activity related to emotional stimuli (see Goldstein, 1968; Herd, 1972; Kalat, 1998; Schachter & Singer, 1962). According to James' theory, individuals would need to differentiate certain aspects of physiological activity to determine which emotion they are feeling. In contrast, Cannon's theory allows for similar physiological reactivity to numerous emotions. While this debate still exists, some research has documented that certain physiological responses are related to specific emotions. For example, Collet and colleagues (1997) found that six specific emotions, including happiness, surprise, fear, anger, sadness, and disgust, could be meaningfully differentiated using a combination of electrodermal, thermovascular, and respiratory measures. Furthermore, numerous studies

by Levenson and colleagues have demonstrated that different emotions are associated with different patterns of autonomic nervous system (ANS) activity (for a review see Levenson, 1992). These differences include greater increases in heart rate during anger and fear as compared to happiness, and greater increases in skin conductance during fear and disgust as compared to happiness. With respect to differences among negative emotions, feelings of anger, fear, and sadness are associated with increases in heart rate whereas feelings of disgust are associated with a decrease in heart rate.

Carels and colleagues have reported that increases in ambulatory blood pressure and heart rate are significantly related to negative emotions experienced throughout the day in individuals with high variability in the frequency and magnitude of diary ratings of negative and positive mood (i.e., high emotional responders) (Carels et al., 2000). Similar research has demonstrated that high emotional responders are also 2.5-4 times more likely than low emotional responders to experience myocardial ischemia during daily life as well as during laboratory induced mental stress (Carels et al., 1999). These findings indicate that the degree to which individuals respond emotionally to a given stimulus influences the magnitude of cardiovascular functioning.

Although a wide range of studies supports the ability to distinguish emotions via cardiovascular reactivity, some researchers have been unable to demonstrate differential reactivity to specific emotions. Neuman and Waldstein (2001), for example, employed the circumplex model of emotion while examining cardiovascular reactivity during emotional activation, using a verbal (speaking) recall task. Both arousal and valence dimensions of the induced emotions were assessed. Each emotional task produced significant alterations in systolic and diastolic blood pressure (SBP, DBP), heart rate,

total peripheral resistance, stroke index and cardiac index. However, the only differentiation of emotional valence was a large increase in SBP during negative emotions, as compared to positive emotions; and the only differentiation of emotional arousal was a longer pre-ejection period (an impedance cardiography-derived measure of lower sympathetic nervous system activity) during low arousal. The authors propose that the lack of specificity of the hemodynamic responses to different affective and arousal-inducing stimuli may have been caused by the use of a speaking task as opposed to a non-verbal task. In other words, general motor activation from speaking may have generated the similar hemodynamic responses observed. Therefore, in the current study, only non-oral components of emotional tasks (i.e., visualization portion of emotional recall and computer-based Stroop color word task) will be used. The study will examine the relationship between specific emotional arousal, ANS reactivity, and brain lateralization activity.

Heart Rate Variability

Autonomic nervous system activation during emotion-provoking tasks can be evaluated by heart rate variability (HRV). HRV is based on respiratory sinus arrhythmia (RSA), which is the heart beat rhythm, as depicted by the variance of the R-R interval on the electrocardiogram (ECG), associated with respirations. RSA is one measure of ANS activity and reflects the body's natural change of HR during breathing. The magnitude of change in HR with breathing is driven by the parasympathetic nervous system, such that higher levels of HRV indicate appropriate fluctuations in ANS activation via vagal tone.

The higher the HRV, the more capable the heart is of adapting to stressors, such as increases in physical or mental activity, and reductions in activity. Blunted HRV may indicate a decreased ability for the heart to compensate or react appropriately during stressful or otherwise demanding situations (Porges, 1992). Evidence suggests that depressed HRV predicts future adverse health outcomes, such as cardiac morbidity and mortality in high-risk populations (see Task Force, 1996).

Two types of methods are typically used to assess HRV, time domain methods and frequency domain methods. When using time domain methods, the intervals between normal beats are assessed (NN intervals or R-R intervals) and variables, such as the mean NN interval, difference between the longest and shortest NN interval, and standard deviation of the NN interval (SDNN), are calculated. Frequency domain methods are discussed in detail below. When conducting short-term analyses of HRV, frequency domain methods are preferred to the time domain methods. Frequency domain methods allow for an easier interpretation of precise physiological regulation over shorter time periods, whereas time domain methods account for the instability of heart rate alterations over long-term recordings and are therefore better suited for analysis of longer time periods (Task Force, 1996). Because the current study analyzes HRV over 5 minute intervals, frequency domain analyses were used.

The use of spectral analysis of HRV allows for the direct measurement of ANS responses and activation in field and laboratory settings (Pomeranz et al., 1985; Task Force, 1996). Spectral analysis of the R-R intervals of the QRS complex is used to assess HRV in the frequency domain. Three distinct frequency domains are used to document parasympathetic (PNS) and sympathetic (SNS) input to the heart (Task Force, 1996).

The low frequency (LF) component is typically within the .04-.15 Hz range. In studies examining the link between ANS activity and HRV in dogs and in humans, research has indicated that blockade of both the PNS and SNS separately produce decreases in the LF component (Akselrod et al., 1981; Pomeranz et al., 1985). Therefore, the LF component reflects a combination of sympathetic and parasympathetic activation (McCraty et al., 1995; Task Force, 1996). The mid-frequency component (MF; .08-.15 Hz) has also been used to represent a combination of ANS activity, exhibiting a stronger expression of parasympathetic input (particularly the baroreflex component). However, concerns have been raised regarding its physiological correlates, therefore, the present study will not investigate this range (Task Force, 1996). The high frequency component (HF; .15-.4 Hz) is the most clearly characterized frequency domain. Research regarding the autonomic correlates of HRV has consistently found a link between PNS activity and the HF component. For example, in dogs and in humans, PNS blockade, but not SNS blockade, in both supine and standing positions leads to the elimination of the HF peak (Akselrod et al., 1981; Malliani, Pagani, Lombardi, & Cerutti, 1991; Pomeranz et al., 1985; Rimoldi et al., 1990). Therefore, the HF component solely represents vagal tone, as produced by parasympathetic nervous activity (Task Force, 1996). Another commonly used feature of HRV is the LF/HF ratio. This measure uses the HF component to remove the parasympathetic aspect of the LF component and is a more precise indicator of sympathetic activation and sympathovagal balance. Total HRV is a combination of the low, mid and high frequency components, and is equivalent to the overall variation in heart rate. In the present study, the LF, HF, LF/HF ratio, and total HRV components will be assessed.

Emotions and Heart Rate Variability

When assessing the effects of negative emotional processing on parasympathetic and sympathetic activity in relation to specific personality trait characteristics, Demaree (2004) found that only individuals with low hostility scores demonstrated a decreased sympathovagal response, as assessed by LF/HF ratio, to negative emotions. However, both high and low hostility individuals showed a decreased parasympathetic response (as assessed by RSA rather than specific frequency components) to negative emotional stimuli. McCraty and colleagues (1995) documented that anger in a normal sample elicited an increase in the low frequency and LF/HF ratio components of HRV, suggesting anger-related disruption of sympathovagal balance caused by an increase in the sympathetic contribution. Appreciation, on the other hand, elicited an increase in the medium frequency component and slight increase in the LF component, suggesting more parasympathetic than sympathetic activation during the positive emotion.

In addition to acute emotional responses, longer-term mood has also been associated with HRV. For example, depression has been shown to be associated with blunted HRV (Musselman, Evans, & Nemeroff, 1998). Moreover, in coronary artery disease (CAD) patients receiving coronary artery bypass surgery, depression/negative mood was associated with decreased preoperative HRV (Hallas et al., 2003). Keeping in mind the relationship between reduced HRV and increased cardiac morbidity and mortality among at risk populations, the relationship between emotions and HRV may be used to explain pathophysiological pathways by which negative affect predicts adverse

cardiovascular (CV) health outcomes. Such knowledge may result in development of prevention and intervention programs designed to optimize emotional processing, resulting in better cardiovascular health. The present study will assess the degree to which positive and negative (i.e., happy and angry) emotions affect ANS activation, as mediated by emotion-induced lateralization of brain activity.

Emotions and Brain Activity

As previously mentioned, the experience of an emotional state is associated with physiological, biological, behavioral, and cognitive responses (Taylor, 1991). Included in these associations is concomitant brain activation. During the presentation of emotional stimuli, the most commonly activated brain structures include the frontal cortex, limbic system, and basal ganglia (Cacioppo, 1990; Guyton & Hall, 1996; Kalat, 1998; Patterson & Schmidt, 2003; Phan et al., 2002). The frontal lobe contributes substantially to the awareness, integration, and expression of emotions as well as the production of overt behaviors related to emotions (Davidson, 2004; Kalat, 1998). The limbic system and basal ganglia are interrelated and include the hippocampus, septum, cingulate cortex, putamen, globus pallidus, caudate nucleus, and amygdala and areas of the thalamus and hypothalamus. As will be discussed, these structures have all been implicated in aspects of emotional processing, particularly those aspects related to identification of emotional stimuli and emotional memory (Kolb, 1996). The thalamus serves as a neural conductor between the limbic system, basal ganglia and frontal cortex, among other connections (Kolb, 1996). While emotional processing impacts a number of

cortical and subcortical structures, areas of the hindbrain, and eventually the autonomic nervous system, are also influenced by emotions. According to some research, "cells in the limbic system, particularly in the hypothalamus and amygdala, interpret emotionally significant events and send messages to cells in the medulla and pons [of the hindbrain], which relay the messages to the spinal cord controlling sympathetic [and parasympathetic] nervous activity"(Jansen et al., 1995; cited in Kalat, 1998). Consequently, signals from the hypothalamus and cortex can influence most autonomic related activities controlled by the brain stem (Guyton & Hall, 1996). Therefore, there appears to be a direct link between emotional processing and physiological reactivity.

In addition to cortical activation by general emotional processing, numerous studies have analyzed the relationship between changes in specific emotional states and concomitant brain activation, with varied results (for reviews see Phan et al., 2002; Hagemann, Waldstein, & Thayer, 2003; Coan & Allen, 2004). While it is widely accepted that multiple cortical and subcortical regions, such as the frontal cortex, limbic system, and basal ganglia, are involved in emotional processing, the specific areas of the brain that are activated during particular emotions are not as clear. Much of the variation in this literature can be attributed to the differences in the conceptualization, induction, and measurement of emotion as well as the differences in the type and quality of measurement of brain activity. Despite the diversity of these variables, results suggest a somewhat consistent pattern of cerebral responses to emotional stimuli in general.

In a meta-analysis of studies analyzing the relationship between emotion and brain activation, as measured by positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), Phan and colleagues (2002) found that no particular

brain region was reliably activated by different emotions, or across differing emotional induction methods. These induction methods included viewing pictures or film clips, and/or using autobiographical recall or imagery techniques intended to elicit specific emotions. However, the medial prefrontal cortex (PFC) was the most commonly activated region and was not solely associated with any explicit emotion or induction method. Studies by Lane and colleagues (1997a, 1997b) support these findings and also indicate substantial overlap in activation of the thalamus and midbrain as well as the PFC during both general pleasant and unpleasant emotional tasks and specific happiness, sadness and disgust tasks.

However, both studies by Lane and colleagues did find that regional activation was valence (i.e., positive versus negative affect) dependent. For example, only pleasant emotions elicited activity in the head of the caudate nucleus, whereas unpleasant emotions activated left lateralized portions of the amygdala and hippocampus and bilateral portions of the occipito-temporal cortex and cerebellum (Lane et al., 1997b). Only happy-inducing tasks produced an increase in bilateral activation of the hypothalamus, globus pallidus, medial posterior cingulate, ventral anterior cingulate and ventral mesial frontal cortex. Sadness-inducing tasks activated the amygdala bilaterally, and both sadness and disgust inducing tasks activated the lateral cerebellum (Lane et al., 1997a). Results from both studies indicate activation of the caudate nucleus and globus pallidus during positive emotions and activation of the amygdala during negative emotions. Fear has also been associated with activation of the amygdala, whereas happiness has been associated with activation of the ventral striatum and putamen (Phan et al., 2002).

With respect to emotional tasks that generate cognitive demand (i.e., tasks that involve active rather than passive experience of emotions, such as recall tasks), the anterior cingulate cortex is engaged specifically during cognitively demanding tasks, whereas the PFC is activated during tasks with and without cognitive demand. These two structures may work together as "top-down modulators of intense emotional responses" (Phan et al., 2002). These findings imply that some aspects of emotional processing, such as attention, appraisal or identification of emotional content, represent general cognitive processes that may be shared across emotional tasks. Thus, activation of some brain regions may or may not depend on the specific affective component of emotion.

Emotions and Brain Lateralization

Neuroanatomical research on emotion has also focused on whether or not the valence (i.e., affective) components of emotion elicit lateralized differences in brain activity. Most models propose that emotions produce specific activation in either the left or the right hemisphere. An early model by Tucker (1981) proposed that the right hemisphere was the mediator for all basic emotions (cited in Lane et al., 1997a) . A second model states that each hemisphere has a primary role in processing emotion based on the valence component of the stimulus. In this model, known as the "valence hypothesis," the left hemisphere is predominantly activated during positive emotions, whereas the right hemisphere is principally responsible for processing negative emotions (see Sackeim et al., 1982; Silberman & Weingartner, 1986). This model was primarily developed using results from clinical populations, including patients with lesions and

other forms of brain damage (Jones & Fox, 1992). Lesions of the left hemisphere were associated with greater levels of depression and pathological crying, whereas lesions of the right hemisphere resulted in euphoric mood change and pathological laughing (Sackeim et al., 1982; Silberman & Weingartner, 1986). These changes in emotional processing suggest that the activation of the undamaged, opposite hemisphere is potentially overactive because it is left "unchecked" by the damaged hemisphere. Therefore, individuals with left hemisphere lesions are unable to produce positive emotions to counteract the right hemisphere's production of negative emotions, potentially resulting in depression and constant crying.

More recent research on the valence model has yielded mixed results, such as those found in the work by Lane and colleagues (1997a, 1997b). However, one explanation for these discrepancies is that the level of arousal experienced during each emotional task may be confounding the results. If arousal level is not held constant, the degree to which the lateralization is caused by a positive or negative affective stimulus may not be detectable over and above the effects related to the arousal component. Canli et al. (1998) reported that even when accounting for level of emotional arousal, the left hemisphere appears predominantly activated during the viewing of positive pictures, whereas the right hemisphere is dominant in responding to negative pictures. Although this lateralization was not complete (i.e., there was some activation in both hemispheres during each emotion), these results lend substantial support to the valence hypothesis.

A third model attempting to explain the relationship between emotion and brain lateralization, proposed by Davidson (1992), divides emotions into two motivational systems, specifically into approach and appetitive emotions versus withdrawal and

avoidance emotions. This approach/withdrawal motivational model posits that left frontal lateralization is associated with approaching or engaging in a stimulus, whereas right frontal lateralization is associated with withdrawing or disengaging from a stimulus (Coan & Allen, 2004; Davidson, 1992). Several studies have examined this relationship, with seemingly more consistent results than those found in the valence hypothesis literature (for review, see Coan & Allen, 2004).

Greater right frontal activation at rest is associated with experiencing more intense negative affect during a negative film clip (Coan & Allen, 2004; Tomarken, Davidson, & Henriques, 1990). Right frontal activation also occurs when individuals are asked to use their own faces to represent withdrawal emotions, such as fear and sadness (Coan, Allen, & Harmon-Jones, 2001). Viewing films designed to elicit feelings of disgust (withdrawal emotion) also produces relative right hemisphere activation, whereas films depicting happy scenes (approach emotion) produce more left hemisphere activation (Davidson et al., 1990). Even research with infants suggests basic approach behaviors, such as viewing "happy faces," tasting sugar flavored water, and reaching for a parent, are associated with left frontal activation, whereas right frontal activation in infants is associated with crying during separation from a parent and being rated as more irritable and insecure (Davidson & Fox, 1982, 1989; Fox & Davidson, 1986).

A study by Jones and Fox (1992) found that individuals were more likely to endorse approach emotions during video representations of anger and happiness and more likely to endorse withdrawal or avoidance emotions during films depicting sad or disgust. In accordance with both the approach/withdrawal model and the valence hypothesis, relative left lateralization occurred more during the happy video than the sad

or disgust video, and more relative right lateralization occurred during the sad and disgust video than during the happy film. In the same study, the overall pattern of results indicates that individuals who report higher levels of positive affect exhibit higher left hemisphere activation, whereas those who display higher levels of negative affect exhibit more right hemisphere activation. Again, these findings support both the valence hypothesis and the approach/withdrawal motivational model. In addition, this study revealed a complex array of results related to the valence of the video and the experienced level of motivation (approach/withdrawal). For example, individuals who scored high on the negative affectivity (valence) and withdrawal (motivation) ratings demonstrated more right temporal and parietal activation during the disgust film. Those who exhibited more positive affectivity (valence) and approach (motivation) to the disgust video had increases in left temporal and parietal and right frontal activation. According to the valence hypothesis, the disgust film, an affectively negative stimulus, should elicit the same level of (right) lateralization, regardless of the magnitude of individual affectivity and motivational ratings. Therefore, these results suggest that more factors other than valence alone influence lateralization. In the present study, two approach stimuli, one negatively valenced (anger) and one positively valenced (happy), will be used to further elucidate the effects of affect on lateralization.

Brain Lateralization and Autonomic Nervous System activity

In addition to lateralized emotional processing in the brain, research has demonstrated differential effects of left versus right brain activation on autonomic

nervous system activity (for review, see Lane & Schwartz, 1987; Wittling et al., 1998a; Wittling et al., 1998b). Both sympathetic (SNS) and parasympathetic (PNS) *right-sided* innervation of the heart, including the SA-node, exerts control over chronotropic cardiac activity, as demonstrated by heart rate. *Left-sided* innervation by the SNS and PNS, on the other hand, exerts control over atrioventricular (AV) conduction (dromotropic activity) and myocardial contractility (inotropic activity). These asymmetrical differences originate at the level of the brain stem, with the nuclei in the right brain stem predominantly controlling chronotropic activity and the left-brainstem nuclei controlling dromotropic and inotropic activity. However, the picture is not as clear when assessing input by the cerebral cortex.

While some research demonstrates that cortical mechanisms of sympathetic control are a function of the right hemisphere, other research points to right hemisphere cortical control of heart rate acceleration and, in some cases, myocardial contractility (Wittling et al., 1998a; Wittling et al., 1998b; Zamrini et al., 1990). Heart rate deceleration, purportedly a function of PNS input, may be under left hemisphere cortical control (Wittling et al., 1998b). However, these results have not been reliably demonstrated and are confounded by the sympathetic nervous system effects on heart rate. In a study by Wittling et al. (1998a), hemispheric control of vagal input to the heart, as assessed by measures of HRV, was examined. Right-handed, healthy participants were presented with film stimuli to either the right visual half field (left hemisphere) or the left visual half field (right hemisphere) while their HRV was assessed. The films that were used depicted either negative or neutral scenes, with no positive films included. The results indicate that activation of the left cerebral hemisphere was related to increases

in the HF component (a marker of PNS activity) as well as decreases in LF/HF ratio (indicator of sympathovagal balance). Additionally, right hemisphere activation was associated with higher levels of LF/HF ratio, indicating right hemisphere dominance in SNS activation. Although these results are promising, they should be viewed with caution because the emotional content of the films was not taken into consideration.

Brain Lateralization and ANS activation during Emotions

In studies using electroencephalograph (EEG) measures of CNS activity in relation to ANS activation during emotions, researchers have found that bilateral activation of the midfrontal cortex and right lateralized activity of the precentral cortex during sadness, and left lateralized activity during relaxation are similarly associated with changes in heart rate (De Pascalis, et al., 1998). Waldstein and colleagues (2000) assessed EEG and CV reactivity during happiness and anger inducing tasks, using both emotional film clips and personally-relevant recall tasks to elicit emotions. Happiness-inducing tasks produced relative left lateralization, while overall right lateralization and CV responses did not differ by emotion. Results further indicated a relationship between frontal cortex activation, both for the left and right hemisphere, and an increase in HR reactivity during the anger tasks. In addition, those who displayed more right frontal activation during the anger tasks exhibited greater systolic and diastolic responses than those without lateralization. These findings indicate a possible connection between lateralization during emotional tasks and ANS responses, as assessed by CV reactivity.

Hagemann, Waldstein, and Thayer (2003) reviewed the recent literature concerning the central and autonomic nervous system correlates of emotion. Earlier work supports the notion that the right hemisphere is dominant in control of autonomic responses to emotion, but subsequent investigations indicate a complex model of interaction between the CNS and ANS when examining emotional reactivity. In studies of patients with brain lesions, the role of the right hemisphere as the mediator of ANS responses to emotion is partially supported. However, some research on patients with more distinct lesions provides evidence that both hemispheres are involved in the association between emotion and ANS activity. The findings of lesion studies are possibly confounded by the small sample size and the inability to determine precisely which areas of the brain the lesions impinge on as well as the interdependence of different brain areas for proper CNS function (Hagemann et al., 2003).

With respect to research in healthy participants, several studies using visual stimuli presented to one hemisphere at a time have supported the theory that the right hemisphere controls heart rate responses to unpleasant stimuli (see Wittling et al., 1998a). However, research related to heart rate responses to pleasant stimuli is less clear (Hagemann et al., 2003). Results from neuroimaging studies using PET are also ambiguous. A study by Lane and colleagues (2000) demonstrated a positive correlation during emotional arousal (during positive and negative tasks) between decreases in HRV and decreases in activation of the medial PFC and left posterior orbitofrontal/anterior insular cortex.

Some studies have found a positive correlation between left lateralization and increases in skin conductance (an indicator of sympathetic activation) during pleasant and

unpleasant stimuli. Other neuroimaging studies have found that activation of right frontal lobe, insular, anterior temporal lobe, and extrastriate cortex is associated with increases in skin conductance responses during both pleasant and unpleasant emotions (Hagemann et al., 2003). These findings suggest that dichotomizing left and right brain activation in response to emotional stimuli may require additional CNS assessment to fully document determinants of ANS responses.

Lane and Schwartz (1987) propose a mechanism to explain the relationship between intense emotional states and sudden cardiac death that incorporates brain lateralization of ANS and emotional responses. The proposed hypothesis states that those who express greater lateralized CNS responses to emotion may also produce more lateralized cardiac sympathetic or parasympathetic input, thus creating an ANS imbalance that could trigger arrhythmias and lead to an increased risk of sudden cardiac death. More specifically, the experience of negative emotions by lateralized responders, as indicated by greater right hemisphere activation leading to an increase in relative SNS activity, would result in ventricular fibrillation leading to a greater risk of sudden cardiac death. Similarly, greater activation of the left hemisphere (during positive emotions) could produce alterations in PNS activity, resulting in nonuniformity of refractory periods in the ventricle, creating fatal arrhythmogenic effects. Thus, both positive and negative emotions may trigger sudden cardiac death, but via different brain-heart pathways.

Purpose and Hypotheses of the Present Investigation

The current study assessed ANS (HRV) and CNS (frontal lobe EEG) responses to approach-related positive and negative emotions (happiness and anger) in healthy

participants. The study was based on analyses of an archival data set. The following hypotheses, based on the model presented in Figure 2, were tested:

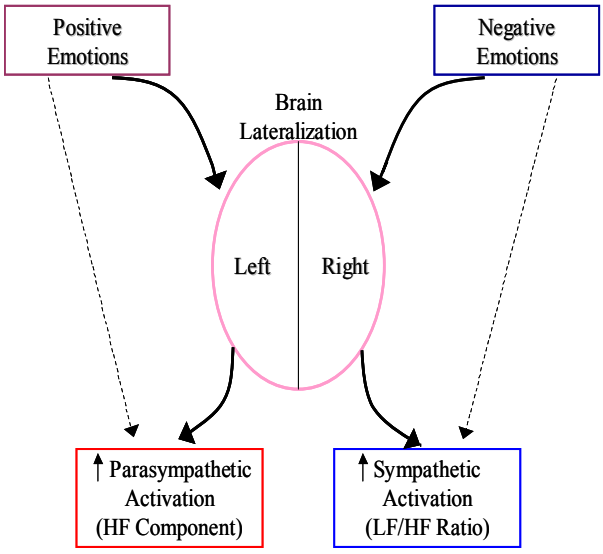


Figure 2: Study Model

1(a) During tasks inducing negative emotions (anger recall task and stress-inducing Stroop), the level of negative emotion expressed (anger) will be associated with sympathetic activation (LF/HF ratio increase).

1(b) During tasks inducing positive emotion (happiness recall task), the level of positive emotion expressed (happiness) will be associated with parasympathetic activation (HF increase).

2(a) The magnitude of right brain lateralized neural activity induced by negative emotion (elicited by the anger recall task and stress-inducing Stroop) will be associated with an increase in LF/HF ratio, indicating relative sympathetic dominance and parasympathetic (vagal) withdrawal.

2(b) The magnitude of the left brain lateralized neural activity induced by positive emotion (elicited by happiness recall task) will be associated with an increase in the HF component, indicating relative parasympathetic activation.

3(a) During the anger recall task and stress-inducing Stroop, those who exhibit high negative emotional responses and strong right lateralization (high negative responders) will display a greater shift in LF/HF ratio (demonstrating more sympathetic input) in comparison to those who do not have high negative emotional responses or strong right lateralization.

3(b) During the happiness recall task, those who exhibit high positive emotional responses and strong left lateralization (high positive responders) will display a greater increase in the HF component (demonstrating more parasympathetic input) in comparison to those who do not have high positive emotional responses or strong left lateralization.

Methods

Sample

Thirty university students (60% female, mean age = 23.9 years) participated in the original study. Because the current study used existing data, it did not meet criteria defining human subjects research and, therefore, did not require IRB review (see Memorandum in Appendix A). For the original study, participants were recruited from the University of Maryland College Park campus. Participant selection was not gender or race specific and included healthy, right-handed individuals. Right-handed individuals were selected to control for the known effects of cerebral laterality (as reflected by handedness) on EEG activity (Papousek, 1999). Results on blood pressure and HR as related to EEG responses have been described previously (Waldstein et al., 2000). The present study examines specific ANS responses as measured by HRV. To control for extraneous influences on cardiovascular and cerebral activity, the following exclusion criteria were used: 1) Type I or Type II diabetes; 2) history of any cardiovascular disease or hypertension; 3) psychiatric disorder; 4) history of head injury with loss of consciousness >10 minutes; 5) obesity (>25% overweight by Metropolitan Life Insurance Tables) (Metropolitan Life Insurance Company, 1983) and 6) use of medications that affect cardiovascular or cerebrovascular function. HRV data for 20 participants were available for analysis in the present study. There were no significant differences in baseline cardiovascular and lateralization parameter's between participants with (N=20) versus without (N=10) HRV data (see Table 1).

Procedure

The study outline is summarized in Figure 3. Participants performed a positive recall task, a negative recall task, and a computerized stress-inducing Stroop task. After providing informed consent (Appendix B), participants were randomly assigned to one of two groups, receiving either the positive or the negative recall task first and always completing the Stroop task last to reduce carry over effects (see Figure 3). The Stroop task was designed to produce adverse affect and also included mild harassment by the research assistant to invoke a stronger emotional response. Each task lasted for a total of 5 minutes with a 10-minute rest period in between tasks. Recall tasks consisted of 3 minutes of verbalized recall and 2 minutes of visualization.

After completing a brief demographic questionnaire, participants were fitted with the EEG stretch cap (Electro-Cap Inc.) and the Critikon Dinamap (Model #8100) automated vital signs monitor (Critikon, Tampa, FL) and began the emotional induction tasks after a 10-minute rest period. Baseline EEG data and CV measures (including HRV) were taken at minutes 7-9 of the initial rest period to allow participants to acclimate to the laboratory environment. Recall tasks were separated into speech and visualization portions (Instructions are provided in Appendix C). This was done to reduce the well-known effects of speaking on EEG measures. Therefore, the EEG was only recorded during the non-speech 2-minute visualization epochs of the recall tasks.

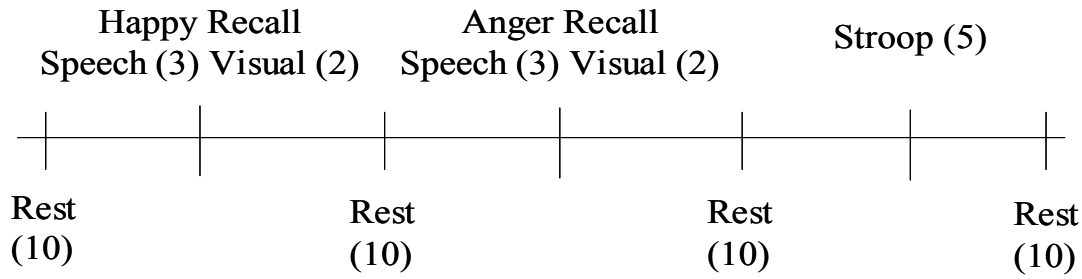


Figure 3: Procedural timeline

During the recall tasks, participants were instructed to verbally describe and then imagine a personally-relevant, happiness- or anger-inducing event that had occurred within the past 6 months (Ironson et al., 1992). The participants were asked to recreate the incident including what was said and done, and what they thought and felt, with as much detail as possible. During the visualization portion, participants were asked to continue thinking about the situation, focusing on visualizing specific aspects, such as the location and who was present, while concentrating on their associated feelings. After each emotional induction, participants rated the intensity of different emotions on a 10-point Likert scale. Participants were then instructed to remain calm and relax during the 10-minute rest periods.

For the computerized Stroop color-word task, participants were asked to press a mouse button (with their dominant hand) corresponding to the display color (blue, red, or green) of the presented word as fast as they could when color words ("red", "blue", or "green") appeared on the computer screen. The answers were three color words ("red", "blue", and "green") displayed in a mismatched color (red, blue, or green). Participants were instructed to respond to the display color of the target word by selecting the corresponding written word on the lower part of the screen. For example, if the target word "blue" was presented in red display color, then the three possible answers were the words "blue" displayed in red letters, the word "green" displayed in blue letters, and the word "red" displayed in green letters; the correct response would then be "red" written in green letters. Participants were told to get as many correct answers as possible in the allotted time and were "harassed" by the research assistant to enhance negative affect.

The study also included viewing and separately rating a happiness inducing video, anger provoking video, and disgust provoking video, but these tasks did not elicit strong cardiovascular responses and lasted less than 90 seconds, precluding HRV analysis. Therefore data from these tasks are not included in the analyses described in this thesis.

Measures

To evaluate the intensity of the affective components of emotional responses, 10-point Likert scales were used, assessing subjective "happy" and "angry" emotions. Likert scales of "involvement" and "interest" assessed the arousal component of emotion. These ratings were obtained during the rest periods prior to each task (creating baseline measures) and immediately post-task for the anger recall, happiness recall, and Stroop tasks. The scale also assessed to what extent each task made the participants feel anxious, depressed, and disgusted. Because of the motivational and affective complexities of these three emotions, these latter emotions are analyzed as a manipulation check only and will not be used for comparisons among hemodynamic and lateralization measures.

Hemodynamic measures, including systolic and diastolic blood pressure, and heart rate, were measured using a standard Dinamap automated vital signs monitor. SBP, DBP, and HR measurements were taken at 90-second intervals during resting periods and at 60-second intervals during all task periods. The last three readings during each resting period were combined into average baseline SBP, DBP, and HR measures. Average recall task values (for visualization and speech portions individually) of SBP, DBP, and HR were obtained using the three readings during the speech portion and the two

readings during the visualization portion of the task. During the Stroop task, the last three readings (minutes 3-5) of SBP, DBP, and HR were combined to produce the average measures. Brain lateralization was assessed by EEG (electroencephalograph) pre task (during the minutes 7-9 of the resting periods), during the visualization portions of the recall tasks (2 minutes), and during the final 3 minutes of the Stroop task.

EEG Measures

Brain electrical activity and lateralization was recorded using a lycra stretch cap (Electro-Cap Inc.). The EEG was recorded at 8 locations, including the left and right mid-frontal, parietal, central and occipital regions. Only the frontal regions are used in these analyses because the frontal region is the most commonly cited region of activation during emotional processing (see sections 5. Brain Activity and Emotions and 6. Brain Lateralization and Emotions). Power (microvolts squared) was computed in the alpha frequency band (8-13 Hz.) for each electrode site, with a decrease in alpha scores indicating an increase in activation (Coan & Allen, 2004). EEG data were analyzed using a discrete Fourier transform, with a Hanning window of 1-s width and 50% overlap. Change scores (mean log transformed task – mean log transformed baseline) were calculated as an index of task-induced left and right frontal lobe responses. A negative change score indicates relative activation.

HRV

Heart rate variability was assessed by ECG using a Holter monitor (Marquette Medical Systems, 8500 Series ambulatory tape recorder) throughout the study and ECGs

were analyzed for single minute epochs before and during each task. A semiautomatic software program (MARS PC 6.01, GE Medical Systems Information Technologies, 2003) was used to divide HRV measures into low frequency (.04-.15 Hz), high frequency (.15-.4 Hz) and LF/HF ratio using spectral analysis by Fast Fourier Transform to separate R-R intervals. The goal was to obtain minute-by-minute analyses for the 3 minutes of verbalized recall, 2 minutes of visualization, 5 minutes of the Stroop, and the final 5 minutes of the resting periods. This program requires a 5-minute time frame for each single minute analysis. R-R intervals of the 2 minutes prior to and 2 minutes following the minute of interest were used to determine HR trends for each single minute of HRV analysis. A logarithmic transform of the power of each frequency band was used to normalize the data and the resultant power is described in $\ln(ms^2)$. Holter tapes were analyzed by hand and all abnormal beats (including supraventricular beats) were removed prior to analysis to obtain a pure index of HRV without irregularities.

Statistical Analyses

For all analyses, α was set at 0.05 (two-tailed). Post-hoc power analyses showed that with a sample size of N=20, the study was powered at the 80% level to detect medium to large effects (Pearson correlation $r = 0.55$ or higher).

For validation of the emotion induction tasks, paired samples t-tests (baseline vs. post-task) of each Likert scale response were conducted to determine if the tasks elicited the expected changes in affective and arousal components of emotion.

Analyses of Hypothesis 1:

Pearson correlations were conducted to determine if the level and type of emotion expressed were associated with the relevant specific components of HRV. The associations of "angry" emotion during the anger recall and Stroop tasks with HRV measures during those tasks were analyzed to specifically address Hypothesis 1(a). Similarly, the association of "happy" emotion during the happiness recall task with changes in the HRV measures during the happiness recall task were analyzed to address Hypothesis 1(b).

Analyses of Hypothesis 2:

Pearson correlations were conducted to determine if the degree of lateralization during each task was associated with specific components of HRV. The associations of right lateralization during the anger recall and Stroop tasks with the LF/HF ratio were analyzed and the association of left lateralization during the happiness recall task with HF component of HRV was analyzed.

Analyses of Hypothesis 3:

To determine if the combination of high emotional responsivity and high lateralization produced the greatest changes in specific components of HRV, participants were divided into either high responders or low responders for each task. Median splits were used to determine group status, with those with the highest lateralization scores and highest emotional responses forming the "high responders" group during each task. Therefore, during the anger recall and Stroop tasks, the LF/HF ratio of those with high

levels of anger and a high degree of right lateralization (Group 1, high negative responders) were compared to the LF/HF ratio of individuals with lower levels of anger, lower levels of right lateralization, or lower levels of both (Group 2, low negative responders). During the happy recall task, the HF component of individuals with high levels of happy emotion and a high degree of left lateralization (Group 1, high positive responders) was compared to the HF component of individuals with either lower levels of happy emotion, lower levels of left lateralization or lower levels of both (Group 2, low positive responders).

To further examine the relationship between emotional and lateralization responses and HRV, two-way ANOVAs were used to assess the differences in HRV between high versus low emotional responders and high versus low lateralization responders. Interaction terms between emotion and laterality were examined. Independent samples t-tests were used to compare high responder groups with low responder groups within each task.

Results

Participant characteristics are presented in Table 1 (age, gender, height, weight, years of education, marital status, race, baseline SBP, DBP, HR, and left and right lateralization). Independent samples t-tests revealed only one difference in demographic characteristics; those with HRV data (N=20) ($\bar{X}$ = 25.05, st. dev. = 4.55) were significantly older than those without HRV data (N=10) ($\bar{X}$ = 21.60, st. dev. = 2.72; t = 2.20, p = .036). Independent samples t-tests comparing those with versus those without HRV data revealed no differences in baseline hemodynamic or EEG characteristics.

Validation of emotion induction:

Self-reported emotions induced by the happiness recall, anger recall and Stroop tasks were in the appropriate direction (see Table 2). The happiness recall task significantly increased feelings of happiness as compared to baseline (t = 4.44, p= 0.001). The angry recall and Stroop tasks significantly increased feelings of anger as compared to baseline (t = 9.09, p = 0.001; t = 3.39, p = 0.003, respectively). The anger recall and Stroop tasks also elicited an increase in anxious scores (t = 4.96, p = 0.036; t = 6.13, p < 0.001) and feelings of disgust (t=6.26, p< 0.001; t = 2.03, p = 0.057), and a decrease in happiness scores (t = 4.58, p < 0.001; t= 2.13, p = 0.047).

Arousal measures included “interested” and “involved” ratings. The happiness recall and Stroop tasks elicited an increase in “interested” scores (t = 3.17, p=0.005; t = 7.102, p <0.001). All three tasks elicited a significant increase in “involved” scores (p< 0.01). These results demonstrate that each emotional task produced the expected changes in both the affective and arousal components of emotion. Positive emotions and

engagement were enhanced during the happiness recall task, whereas negative emotions and engagement were enhanced during the anger recall and Stroop tasks.

Hemodynamic responses:

Systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (pulse) responded significantly to the challenge tasks (see Figures 4 and 5). Each task, including both the speech and visualization portions, elicited a significant increase in SBP ($6.96 > t > 3.09$, p's < 0.006). DBP significantly increased during the speech and visualization segments of the happiness recall task ($t = 7.71$, $p < 0.001$; $t = 2.17$, $p = 0.043$), the speech segment of the anger recall task ($t = 5.44$, $p < 0.001$), and the Stroop ($t = 6.32$, $p < 0.001$). Heart rate increased significantly during the speech portion of the happiness recall task ($t = 3.09$, $p = 0.006$), the speech portion of the anger recall ($t = 6.70$, $p < 0.001$) and during the Stroop ($t = 6.24$, $p < 0.001$).

HRV Responses:

HRV responses to the positive and negative emotion induction tasks are shown in Figures 6, 7, and 8. During the happiness recall task, LF significantly increased from baseline ($t = 3.17$, $p = 0.005$), whereas during the Stroop task, LF significantly decreased from baseline ($t = 3.95$, $p = 0.001$). LF during the anger recall task was significantly lower than during the happiness recall task ($t = 2.51$, $p = 0.021$). During the Stroop task, LF was significantly lower than during both the happiness and anger recall tasks ($t = 3.86$, $p = 0.001$; $t = 4.84$, $p < 0.001$). Similarly, during the Stroop task, the HF component significantly decreased from baseline ($t = 3.79$, $p = 0.001$) and was significantly lower

than during the happiness and anger recall tasks ($t = 3.83$, $p = 0.001$; $t = 3.35$, $p = 0.004$). For the LF/HF ratio, only the Stroop induced significant responses with lower values than during the happiness recall task ($t = 2.31$, $p = 0.033$). Two other trends were apparent, including a lower LF/HF ratio during the Stroop as compared to the anger recall task ($t = 2.01$, $p = 0.06$) and an increase in LF/HF ratio from baseline to task during the happiness recall ($t = 1.85$, $p = 0.08$). The total frequency HRV during the Stroop task decreased significantly from baseline ($t = 5.04$, $p < 0.001$) and was lower than during both the happiness and anger recall tasks ($t = 4.07$, $p = 0.001$; $t = 3.34$, $p = 0.004$).

During baseline measures for all three tasks, heart rate was significantly negatively correlated with HF and total HRV components ($-.63 > r > - 0.46$, $p < 0.05$; see Table 3). During baseline measures of the anger recall and Stroop tasks, HR was also negatively correlated with the LF component ($r = -0.69$, $r = - 0.49$, $p < 0.05$, respectively). SBP during baseline anger recall was positively associated with the LF/HF ratio ($r = 0.46$, $p < 0.05$). During the speech portion of the anger recall task, the LF/HF ratio was negatively associated with both SBP and DBP ($r = -0.50$, $r = - 0.48$, p, 0.05, respectively). During the Stroop task, the HF component was negatively correlated with all three CV measures, SBP, DBP, and HR ($r = -0.46, -0.46, -0.62$, $p < 0.05$, respectively). Also during the Stroop, the LF component was negatively associated with HR and DBP ($r = -0.74, -0.77$, $p < 0.01$, respectively). In general, higher levels of HR during baseline and higher CV reactivity during the task were associated with decreases in HRV. Thus, HRV measures overlap but do not completely coincide with blood pressure and HR measures.

Association of emotional responses with hemodynamic and HRV responses (Hypothesis 1):

During the anger recall task, expression of angry emotion was significantly negatively correlated with heart rate during the speech and visualization portions ($r = -0.54$, $p = 0.014$; $r = -0.44$, $p = 0.05$, respectively), indicating that higher levels of anger expression resulted in lower heart rates. No significant correlations were found between the level of happy emotion expressed during the happiness recall task or the level of anger expressed during the Stroop task and any hemodynamic measures.

During the anger recall task, higher levels of feeling involved were negatively correlated with heart rate during the speech portion of the task ($r = -0.48$, $p = 0.033$). During the visualization portion of the anger recall task, the correlations between the degree of self-rated involvement in the task and systolic and diastolic blood pressure approached significance (r's $= 0.42$, $p < 0.075$). Also, during the speech portion of the anger recall task, expression of interest was positively correlated with increases in systolic blood pressure ($r = 0.51$, $p = 0.02$). There were no correlations between involved or interested scores and hemodynamic measures during the happiness recall or Stroop tasks.

With regards to affective emotional expression and HRV (Hypothesis 1), during the happiness recall task, the level of happiness expressed was significantly associated with an increase in the HF component of HRV, as predicted ($r = 0.56$, $p = 0.011$; see Table 4). Additionally, anger scores and change in anger scores during the Stroop were significantly correlated with the LF/HF ratio during the Stroop, as predicted ($r = 0.65$, $p = 0.002$; $r = 0.60$, $p = 0.007$, respectively). The correlation between the change in anger

expression during the anger recall task and LF/HF ratio revealed a trend towards a negative correlation ($r = -0.39$, $p = 0.089$; see Table 4), indicating that higher levels of anger expression are related to lower levels of LF/HF ratio. This finding is in the opposite direction of Hypothesis 1(a).

With regard to arousal and HRV, during the happy recall task, the change in interested scores was correlated with the HF component of HRV ($r = 0.60$, $p = 0.005$, see Table 4). Also, the correlation between the change in interested scores and LF component approached significance ($r = 0.43$, $p = 0.06$). The change in involved scores was associated with the HF component, the change in the LF component and the change in the LF/HF ratio during the happiness recall task ($r = 0.45$, $r = 0.47$, $r = 0.52$, $p < 0.05$, respectively). During the anger recall task, the change in involvement expressed was negatively correlated with the LF/HF ratio ($r = -0.44$, $p = 0.05$). There were no correlations between involvement or interested scores and any HRV measures during the Stroop task.

EEG responses:

Baseline measures of EEG activity (both right and left lateralization) were not correlated with any baseline or task measures of HRV (r's < 0.36, p's $> .13$).

As predicted, the happiness recall task elicited an increase in left frontal activation in comparison to baseline measures ($t = 2.49$, $p = 0.023$; see Figure 9). However, right brain activation during the anger recall and the Stroop tasks did not differ significantly from baseline measures. When comparing the left lateralization and right lateralization change scores within each task, no significant differences were found (i.e. within each

task, left and right lateralization change scores were not different from one another). Similarly, when comparing left and right lateralization between tasks, no significant differences were found (i.e. changes in left and right lateralization during the happiness recall, anger recall, and Stroop were not significantly different from one another).

Correlations between Emotion and HRV and EEG responses (Hypotheses 2-3).

Hypothesis 2(a) states that right brain activation during the anger recall and Stroop tasks would be associated with an increase in LF/HF ratio, demonstrating a sympathetic dominated response. However, the correlations between LF/HF ratio and right brain lateralization during these tasks were nonsignificant. Hypothesis 2(b) states that left brain lateralization during the happiness recall task would be associated with an increase in the HF component of HRV. Again, analyses did not reveal a significant correlation between these variables (see Table 5).

The final hypothesis proposes that those individuals with the highest emotional responses combined with the highest brain lateralization will have the highest increase in the corresponding HRV response. Therefore, median splits were conducted for both right brain lateralization and anger expression during the anger recall task and the Stroop task. The LF/HF ratio of those individuals with both high anger expression and high right brain lateralization was compared with the LF/HF ratio of individuals with either low anger or low right lateralization or both. The t-test revealed no significant differences in LF/HF ratio or change in LF/HF ratio between the two groups, for both the anger and Stroop tasks. The 2x2 ANOVA also did not reveal a significant interaction between emotional responsiveness and lateralization on HRV (p's > 0.10). A similar median split was

conducted for the happiness recall task, with the HF component of individuals expressing high happy emotion and high left brain lateralization being compared to the HF component of those with lower happy emotion, lower left lateralization or both. This t-test revealed a significant difference between groups, with high emotional and lateralization responders demonstrating a higher increase in HF component ($t= 2.638$, $p = 0.017$; see Table 6). However, the interaction term (emotion x lateralization) did not reveal significance ($p > 0.10$).

Differences in HRV measures between those with high emotional responses only, high lateralization responses only, both or neither, were found using t-tests (see Figures 10- 13). During the anger recall, the individuals who had high emotional responses only (with low lateralization) exhibited a trend towards higher LF ($p = 0.057$) and significantly higher HF ($p = 0.031$) HRV in comparison to those with only high lateralization. During the happiness recall task, there was a trend for those with high emotional responses, with or without high lateralization, to have higher LF scores than those with only high lateralization ($p = 0.062$; $p = 0.083$ respectively). For the HF component, those with high emotional responses had higher scores than those without high emotional responses ($p < 0.04$). There were no significant differences in LF/HF ratio, or during the Stroop task, between high emotional, high lateralization, high both or low both groups. The results of these analyses suggest that individuals who express higher levels of emotional reactivity tend to exhibit higher levels of HRV, during both anger and happy emotional induction tasks.

Discussion

Summary and Implications of Study Findings

The present study examined the relationship between positive and negative emotions, autonomic nervous system activity and brain lateralization. The positive and negative emotional recall tasks and the Stroop elicited the expected emotional and cardiovascular responses. However, the heart rate variability and EEG responses to the emotional tasks revealed a complex pattern of results.

With respect to HRV, the HF component decreased in response to the Stroop task, indicating reduced parasympathetic activity. The happiness recall task did not elicit the hypothesized increase in HF. In contrast, a significant increase in the LF component was observed in response to happiness recall, suggesting at least partial sympathetic activation. This result is consistent with findings of McCraty and colleagues (1995). In that study, the positive, approach-oriented emotion appreciation elicited increases in the mid-frequency and low frequency components of HRV. In contrast to the findings of McCraty et al. (1995), the anger recall task in the present study did not produce the predicted increases in either the LF or LF/HF ratio components. Similarly, the Stroop task did not elicit the predicted increase in LF/HF ratio and surprisingly generated a decrease in the LF component and total HRV power. During the Stroop and the happiness recall tasks, the expression of anger and happy, respectively, was not related to any hemodynamic changes. During the anger recall task, however, increases in anger scores were negatively correlated with increases in HR. This finding implies that the expression of anger is related to reduced cardiovascular reactivity to negative emotional

stimuli. Thus, the nature of the challenge task (happiness recall, anger recall, or Stroop) did not reliably produce HRV responses consistent with the hypotheses. We therefore also examined the magnitude of task-induced emotional responses as related to HRV measures.

Using task induced emotional responses, the first hypothesis was partially confirmed by the positive relationship between the increase in happy emotion during the happy recall task and increases in the HF component. Also, increased reporting of anger during the Stroop task was associated with higher LF/HF ratio, as hypothesized. Expression of anger during the anger recall task was positively related to increases in both the LF and HF components of HRV. Similarly, during the happy recall task, higher levels of happiness were associated with increases in both the LF and HF components of HRV. However, during the anger recall task, a trend was found between increased anger and an associated decrease in LF/HF ratio. Therefore, Hypothesis 1(b) was confirmed by the correlation between expression of positive emotions and increases in parasympathetic activation and Hypothesis 1(a) was partially confirmed by the correlation between expression of anger during the Stroop task and increases in sympathetic activation. Taken together, these results suggest that higher levels of expression of the appropriate emotion (anger during anger recall and happy during happiness recall) result in higher levels of mostly parasympathetic (HF) and some sympathetic (LF) activation. The relationship between anger and the LF/HF ratio during the Stroop task suggests that an increase in a negative emotion during a mental challenge task is associated with an alteration in sympathovagal balance. Lane and Schwartz (1987) had hypothesized that the possible alteration of sympathovagal balance during an intense emotional state may trigger sudden

cardiac death. The present results suggest that it may be the experience of a negative emotion during a stressful state, and not just the experience of an intense emotion, that leads to sympathovagal disruption.

Regarding lateralization during the emotional tasks, the happiness recall task elicited the expected relative increase in left frontal lobe activation as compared to right frontal lobe activation. However, no differences in lateralization were found during the Stroop or anger recall tasks. One explanation for these findings is that we only analyzed EEG results from the frontal cortex. According to Davidson (2004), the frontal cortex is "only part of a larger overall circuit" that is involved in the experiencing and processing of emotion. The use of the left vs. right dichotomy of only the frontal lobe may be too limited and does not take into consideration activation of subcortical or posterior regions (Hagemann et al., 2003). Studies by Lane and colleagues (1997a, 1997b) have found that more similarities exist between the neural substrates of different types of emotions than differences. Also, the frontal cortex may be involved in more general aspects of emotional processing that are not associated with any specific valence or method of induction (Lane et al., 1997a; Lane et al., 1997b; Phan et al., 2002). The use of recall tasks also may have contributed to the lack of an association between anger and lateralization. The memories used to elicit anger may also contain memories of other emotions, thus creating ambiguity and possible withdrawal effects (Canli et al., 1998). Trait anger, considered a negatively valenced approach emotion, has also been associated with left frontal activation (Harmon-Jones & Allen, 1998). Therefore our inability to reveal right frontal activation during the anger recall task is not entirely in contrast with existing literature. This study documents an association between levels of expressed

happiness and left frontal activation, demonstrating that a purely positive valenced, approach emotion does elicit left lateralized processing.

Contrary to the second hypothesis, there were no significant correlations between brain lateralization and HRV measures. According to Taylor's mobilization – minimization hypothesis (1991), emotionally intense events, particularly negative or threatening events, initially produce increases in sympathetic activation, followed by parasympathetic activity aimed at reducing arousal. These physiological reactions occur within seconds of the onset of the emotional stimuli. Our measures of HRV may not have been fast enough to detect these changes or separate the SNS from the PNS activity, particularly during the anger recall and Stroop tasks.

Some studies have found that high emotional responsivity is necessary to detect the relationship between emotions and physiological reactivity (Carels et al., 2000; Carels et al., 1999). According to the findings related to our third hypothesis, high emotional responsivity may also be necessary to detect the relationship between emotion-activated lateralization and HRV. When participants were divided into high vs. low emotional responders and high vs. low lateralization responders, those with both high left lateralization and high positive emotional responses during the happiness recall task produced the highest levels of HF and LF HRV. This finding provides some evidence that a combination of emotional and cortical responses to positive emotion increases HF HRV, signifying parasympathetic activation. No differences were found based on high lateralization and high emotional responses during the anger recall or Stroop tasks. However, upon further analysis, during the anger and happiness recall tasks, those who expressed high emotional responses (high anger during anger recall or high happy during

happiness recall), regardless of the level of lateralization, tended to display the highest LF and HF components of HRV. These findings support the work of Carels and colleagues (2000, 1999) and suggest that the magnitude of emotional response predicts the magnitude of HRV response. Lane and Schwartz (1987) hypothesized that a strong lateralization response during emotional arousal would be associated with more lateralized sympathetic input to the heart. The current results indicate that the emotional responsivity of the individual has more of an impact on ANS activation than does brain lateralization.

Study Limitations

One of the major limitations of this study is the small sample size. While the study was powered to detect medium to large effect sizes (Pearson correlations of r= .55 or higher), smaller, yet important relationships, would not be statistically significant in this study. Moreover, the large number of dependent variables, multifaceted hypotheses, and exploratory nature of the final hypotheses required numerous t-tests and correlational analyses. Thus, the nature of the study analyses substantially elevated the probability of Type I error. Also, the participants were not randomly selected and were required to meet strict inclusion criteria, thus limiting the generalizability of the study findings.

In addition, problems concerning the exact timing of the peak emotional responses and the measures of HRV may have limited the results. As previously mentioned, the physiological responses to emotions are swift and can be short lived (Taylor, 1991). However, HRV analysis requires a 5-minute time frame for each analysis (for each single minute, 2 minutes prior to and following it are incorporated into the

calculations). Therefore, for each minute-to-minute analysis, some overlap occurred. The physiological effects induced by the emotions may not have been strong enough to last for that full 5-minute period. In addition, this limitation may not allow for differentiation of discrete trajectories of SNS and subsequent PNS activity. Our findings of decreases in both the LF and HF components during the Stroop lend credence to this limitation.

Another possible limitation includes the method of emotional induction employed in the current study. Because emotional recall tasks include the use of conscious memory, they may produce more general cognitive arousal as well as activating memory pathways not related to emotional content. Thus, the specific cortical activation by the intended emotions may have been overpowered by the activation of cortical memory pathways (Phan et al., 2002). As previously discussed, certain aspects of emotional processing, such as attention, appraisal or identification of emotional content, may be shared across emotional tasks, thus producing similar levels of brain activity regardless of emotional valence.

Finally, with respect to the lack of lateralization during the anger recall and Stroop tasks, the effects of negative emotions may not be easily detected by frontal lobe EEG measures. As discussed, there may also be activation of both hemispheres during this emotion. The EEG of the mid-frontal region cannot detect the differences in subcortical activation that may be occurring, specifically in the amygdala and hippocampus regions (Phan et al., 2004).

Suggestions for Future Research

In spite of these limitations, some of the findings supported previous research on emotion. Different HRV responses were specific to different emotions, with the happy recall task eliciting an increase in the LF component and the Stroop task eliciting decreases in both the LF and HF components (Levenson, 1992; McCraty et al., 1995). In addition, the magnitude of the emotional responses was related to the magnitude of HRV responses in both the anger recall and happiness recall tasks (Carels et al., 2000; Carels et al., 1999). The experience of positive emotion was associated with a relative increase in left frontal activation (Canli et al., 1998; Coan & Allen, 2004). However, no correlation between lateralization and HRV was demonstrated (Wittling et al., 1998a; Wittling et al., 1998b).

The findings from the present study suggest a need for more research in the area of emotional responsivity, brain lateralization and autonomic nervous system activity. In particular, future research should include larger and more diverse samples to enhance generalizability of the results. Also, inclusion of more diverse emotions, such as disgust, fear, and appreciation, may shed light on the specific cortical activity and subsequent autonomic responses involved in emotional processing. More diverse and intense methods of emotion induction, including film or slide presentation, and use of naturally experienced emotions could also enhance the ability to detect differential CNS and ANS activity. In addition, aspects of subcortical activation, specifically during negative emotion induction, should be assessed using more precise measures of brain activity, such as PET and fMRI. Further, research investigating brain activation in populations

with CV vulnerability, in which HRV predicts health outcomes (Task Force, 1996) may reveal important information related to mental stress-induced cardiac events. This study suggests that positive emotion may have beneficial effects on health outcomes via central nervous system-related effects on the autonomic nervous system.

Tables:

Table 1: Demographic and Baseline Cardiovascular Characteristics

	without HRV (N=10)		with HRV (N=20)	
	Mean	Std. Deviation	Mean	Std. Deviation
Age	21.60	2.72	25.05*	4.55
Gender	Male N = 3, 30% Female N = 7, 70%		Male N = 9, 45% Female N = 11, 55%	
Height (in)	65.15	3.71	67.18	3.68
Weight (lbs)	135.20	21.33	147.89	28.20
Years of education	15.30	2.11	16.58	2.32
Marital status (1=Married, 2= Single)	1.90	.32	1.85	.37
Race	Cauc. N = 10, 100%		Cauc. N = 12, 60% Afr. Am. N = 4, 20% Other N = 3, 20 %	
Baseline SBP (mmHg)	112.60	16.00	114.99	11.48
Baseline DBP (mmHg)	65.66	8.44	62.07	11.17
Baseline HR (bpm)	74.37	9.44	70.71	13.87
Baseline Left Lateralization	2.41	.80	1.90	.79
Baseline Right Lateralization	2.35	.76	1.89	.84

* $p < 0.05$, as compared to without HRV.

Table 2: Emotional responses to tasks.

Emotion	Happiness Recall Baseline	Happiness Recall Task	Anger Recall Baseline	Anger Recall Task	Stroop Baseline	Stroop Task
Happy	5.55 (2.46)	**7.75 (1.97)****	5.20 (2.50)	**3.10 (2.02)****	5.53 (2.52)	**4.37 (2.48)^{t}**
Angry	1.35(.75)	1.15 (.49)	1.15 (.37)	**6.65 (2.80)****	1.25 (.64)	**3.40 (3.00)***
Anxious	2.10 (1.83)	2.15 (1.79)	1.80 (1.28)	**3.85 (2.39)****	1.70 (.86)	**5.35 (2.96)****
Disgusted	1.30 (.80)	1.10 (.31)	1.15 (.49)	**5.35 (3.07)****	1.50 (1.61)	**2.80 (2.53)^{t}**
Depressed	1.40(.75)	1.20 (.62)	1.25 (.55)	**3.25 (2.61)***	1.25 (.55)	1.85 (1.87)
Involved	3.65 (2.39)	**5.50 (2.26)****	3.15 (2.48)	**5.85 (2.16)****	3.20 (2.26)	**7.85 (2.03)****
Interested	4.65 (3.01)	**6.25 (2.31)***	4.45 (2.67)	5.35 (2.76)	4.15 (2.72)	**7.70 (1.72)****

Mean (SD)
** $p < .01$, * $p < .05$, ^{t} $p = .057$, difference from preceding baseline.

Table 3: Correlations between Cardiovascular measures and HRV

Baseline Happiness Recall

Baseline		LF HRV, pre-Happiness recall rest	HF HRV, pre-Happiness recall rest	LF/HF ratio, pre-Happiness recall rest	Total HRV, pre-Happiness recall rest
Happiness recall, SBP	Pearson Correlation	.080	-.226	.412	-.043
Happiness recall, DBP	Pearson Correlation	-.078	-.237	.267	-.164
Happiness recall, Heart Rate	Pearson Correlation	-.310	-.483(*)	.373	-.543(*)

* Correlation is significant at the 0.05 level (2-tailed).

Happiness Recall

Increases from Baseline		LF HRV Happiness recall	HF HRV Happiness recall	LF/HF ratio, Happiness recall	Total HRV, Happiness recall
Happiness recall, speech, SBP	Pearson Correlation	.369	.290	-.070	.441
Happiness recall, speech, DBP	Pearson Correlation	.360	.256	-.012	.318
Happiness recall, speech, HR	Pearson Correlation	.115	-.146	.142	.009
Happiness recall, visualization, SBP	Pearson Correlation	.327	-.086	.324	.229
Happiness recall, visualization, DBP	Pearson Correlation	.038	.185	-.115	-.101
Happiness recall, visualization, HR	Pearson Correlation	.305	-.194	.409	.025

No significant correlations

Table 3 continued

Baseline Anger Recall

Baseline		LF HRV, pre-Anger recall rest	HF HRV, pre-Anger recall rest	LF/HF ratio, pre-Anger recall rest	Total HRV, pre-Anger recall rest
Anger recall, SBP	Pearson Correlation	.106	-.184	.460(*)	-.010
Anger recall, DBP	Pearson Correlation	.251	.077	.190	.010
Anger recall, HR	Pearson Correlation	-.687(**)	-.570(**)	.233	-.634(**)

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Anger Recall

Increases from Baseline		LF HRV Anger recall	HF HRV Anger recall	LF/HF Ratio Anger recall	Total HRV Anger recall
Anger recall, speech, SBP	Pearson Correlation	.056	.371	-.497(*)	-.148
Anger recall, speech, DBP	Pearson Correlation	-.077	.253	-.479(*)	-.300
Anger recall, speech, HR	Pearson Correlation	.120	-.186	.372	-.371
Anger recall, visualization, SBP	Pearson Correlation	.024	.144	-.191	-.184
Anger recall, visualization, DBP	Pearson Correlation	-.029	.175	-.267	-.203
Anger recall, visualization, HR	Pearson Correlation	-.146	-.029	-.064	-.261

* Correlation is significant at the 0.05 level (2-tailed).

Table 3 continued

Baseline Stroop

Baseline		LF HRV, pre-Stroop rest	HF HRV, pre-Stroop rest	LF/HF ratio, pre-Stroop rest	Total HRV, pre-Stroop rest
Stroop, SBP	Pearson Correlation	.100	-.160	.360	.012
Stroop, DBP	Pearson Correlation	-.063	-.242	.248	-.215
Stroop, HR	Pearson Correlation	-.485(*)	-.458(*)	.002	-.598(**)

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Stroop

Increases from Baseline		LF HRV Stroop	HF HRV Stroop	LF/HF Ratio Stroop	Total HRV, Stroop
Stroop, SBP	Pearson Correlation	-.413	-.456(*)	.125	-.019
Stroop, DBP	Pearson Correlation	-.770(**)	-.460(*)	-.397	-.301
Stroop, HR	Pearson Correlation	-.736(**)	-.617(**)	-.062	-.411

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 4: Correlations between Emotional responses and HRV

Happy Recall

Emotion	LF	HF	LF/HF Ratio
Δ Happy	**r = .60****	**r = .56 ****	r = -.03
Δ Angry	**r = -.46***	r = -.23	r = -.25
Δ Involved	**r = .47***	**r = .45***	r = -.29
Δ Interested	**r = .43^{t}**	**r = .60****	r = -.34

Anger Recall

Emotion	LF	HF	LF/HF Ratio
Δ Happy	r = .06	r = -.01	r = .11
Δ Angry	**r = .50***	**r = .58****	**r = -.39^{t}**
Δ Involved	r = .20	r = .39	**r = -.44***
Δ Interested	r = .34	r = .24	r = .08

Stroop

Emotion	LF	HF	LF/HF Ratio
Δ Happy	r = -.26	r = -.18	r = -.16
Δ Angry	r = .32	r = .02	**r = .60****
Δ Involved	r = -.24	r = -.07	r = -.31
Δ Interested	r = .39	r = .32	r = .17

** $p < .01$, * $p < .05$, ^{t} $p < .09$, trend

Table 5: Correlations between Lateralization and HRV

Happy Recall

Lateralization	LF	HF	LF/HF Ratio
Δ Left Hemisphere	r =-.08	r = - .19	r = .19
Δ Right Hemisphere	r = .02	r = -.10	r = .21

Anger Recall

Lateralization	LF	HF	LF/HF Ratio
Δ Left Hemisphere	r = .15	r = .10	r = .06
Δ Right Hemisphere	r = .18	r = .11	r = .09

Stroop

Lateralization	LF	HF	LF/HF Ratio
Δ Left Hemisphere	r = -.30	r = -.24	r = -.11
Δ Right Hemisphere	r = -.20	r = -.12	r = -.15

No significant differences.

Table 6: High vs. Low Brain Lateralization and Emotional Responsiveness

Happiness Recall Only

Responder	LF	HF	LF/HF Ratio
Both Hi Left Lat + Hi Emotion (n=5)	**8.01** (.27)*	**6.80** (.13)**	1.18 (.05)
Lo Left Lat, Lo Emot , or Both (n=15)	7.09 (.24)	5.79 (.21)	1.23 (.03)

Mean (SEM)

** p= .01, * p= .05, difference from Low Responders

Anger Recall Only

Responder	LF	HF	LF/HF Ratio
Both Hi Right Lat + Hi Emotion (n=6)	7.21 (.24)	6.06 (.27)	1.20 (.04)
Lo Right Lat, Lo Emot, or Both (n=14)	7.05 (.25)	5.94 (.26)	1.20 (.02)

Mean (SEM)

No differences

Stroop

Responder	LF	HF	LF/HF Ratio
Both Hi Right Lat + Hi Emotion (n=2)	7.02 (.26)	5.85 (.33)	1.20 (.03)
Lo Right Lat, Lo Emot, or Both (n=17)	6.29 (.25)	5.48 (.24)	1.16 (.02)

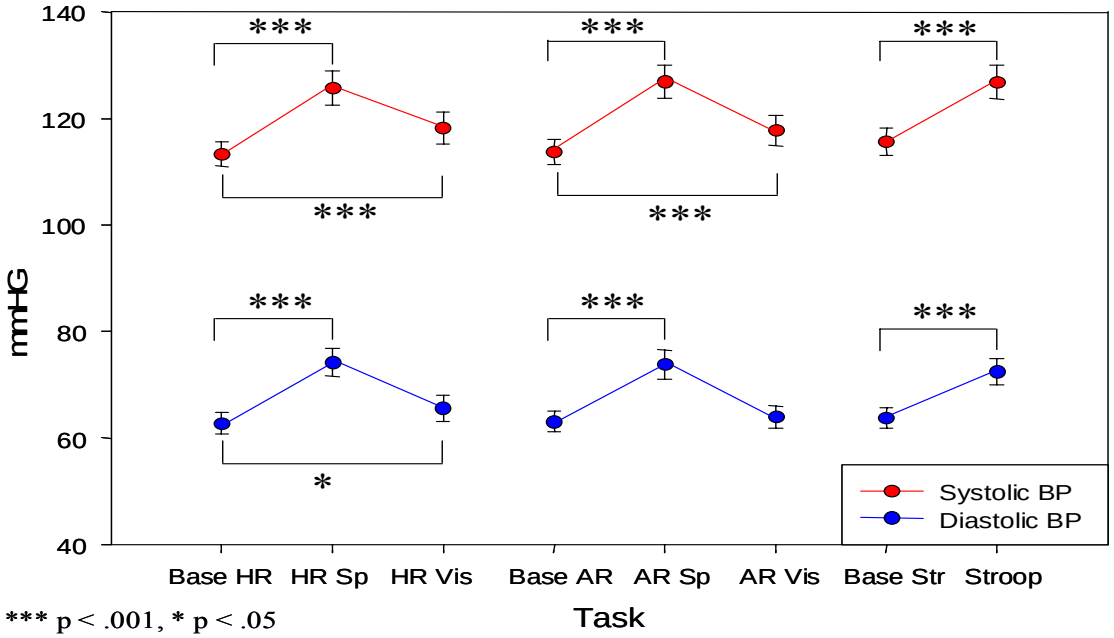
Mean (SEM)

No differences

Figures:
For all figures:

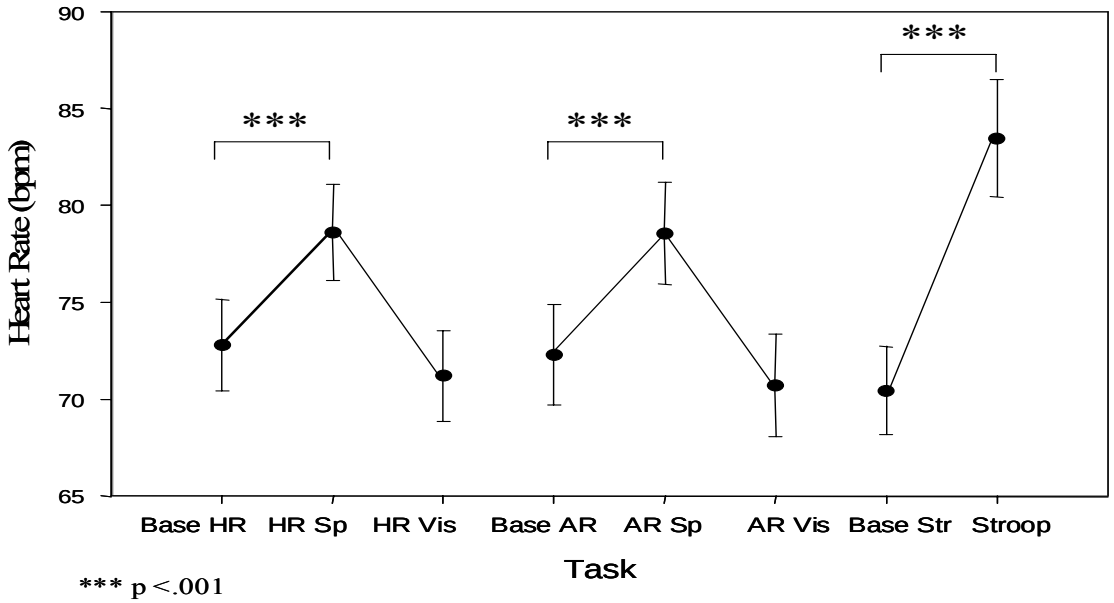
Happiness Recall = HR	Baseline = Base	Lateralization = Lat
Anger Recall = AR	Speech = Sp	
Stroop = Str	Visualization = Vis	

Figure 4: Blood Pressure Responses to Tasks



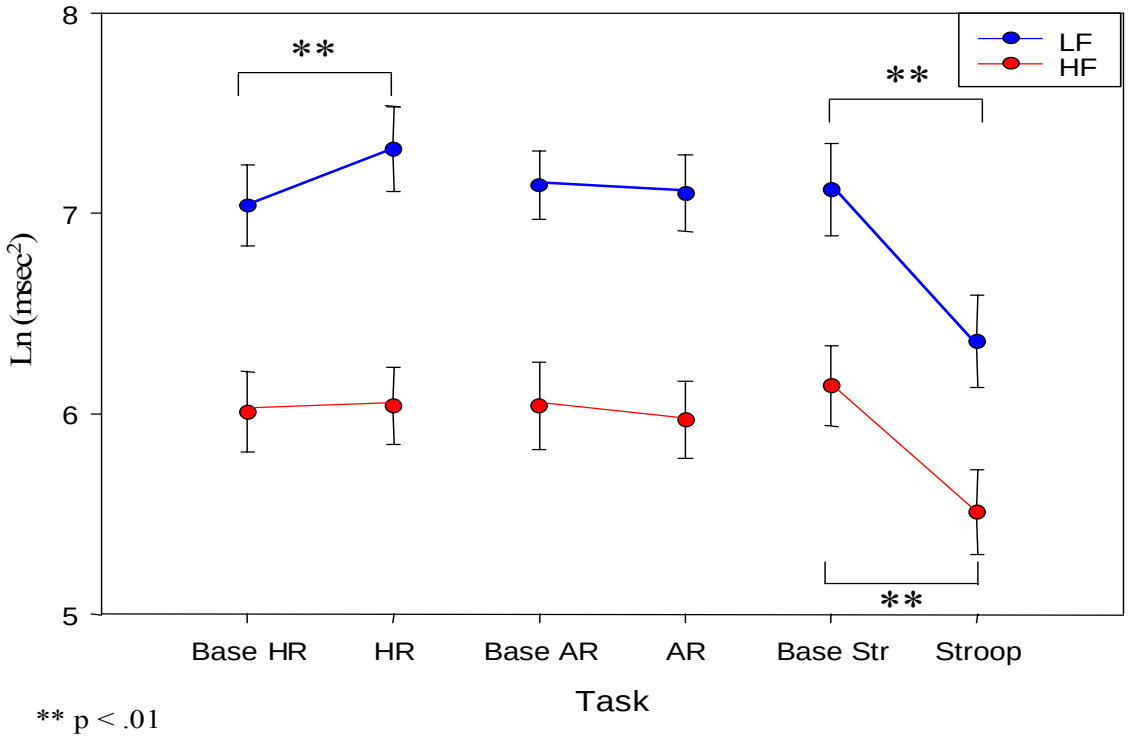
*** p < .001, * p < .05

Figure 5: Heart Rate Responses to Tasks



*** p <.001

Figure 6: LF and HF HRV Responses to Tasks



** p < .01

Figure 7: LF/HF Ratio Responses to Tasks

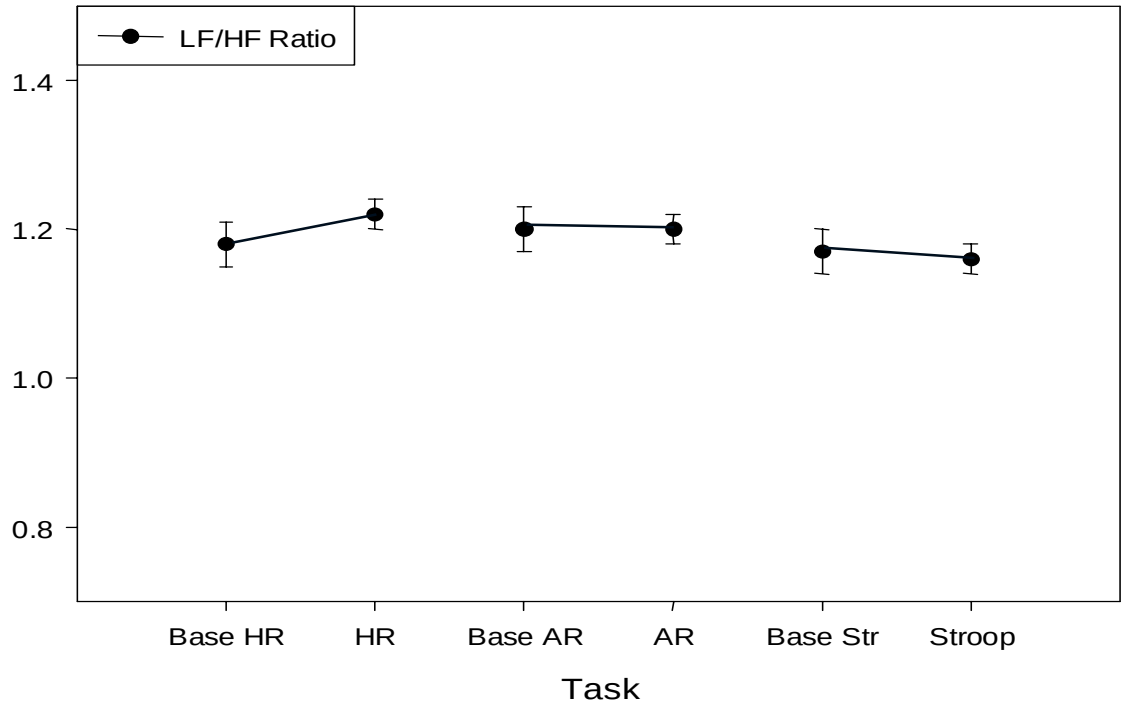
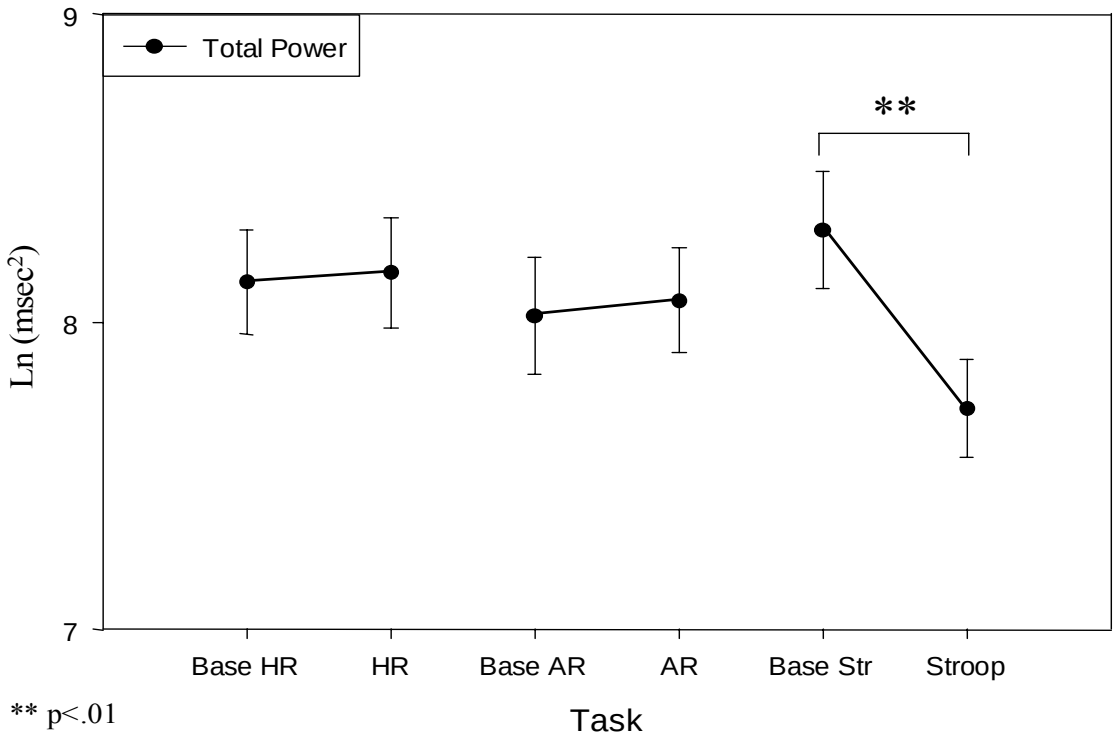
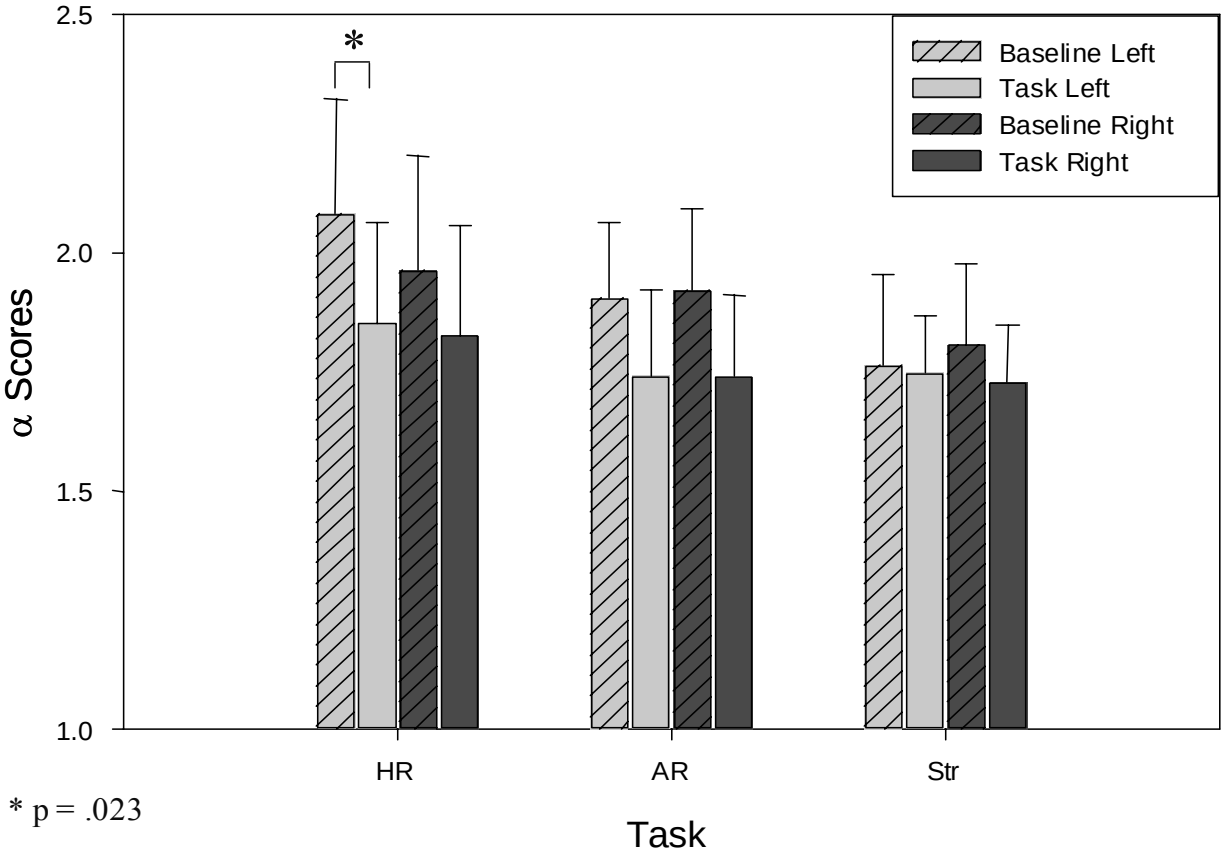


Figure 8: Total Power HRV Responses to Tasks



** p<.01

Figure 9: EEG Responses to Tasks



* p = .023

Figure 10: High vs. Low responders, LF component, Anger Recall.

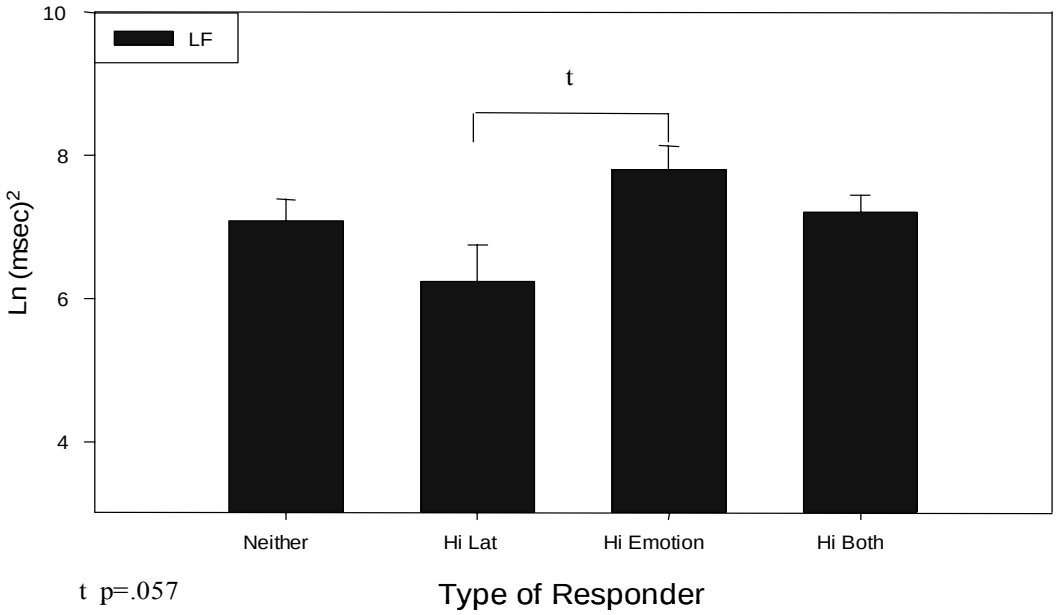


Figure 11: High vs. Low responders, HF component, Anger Recall.

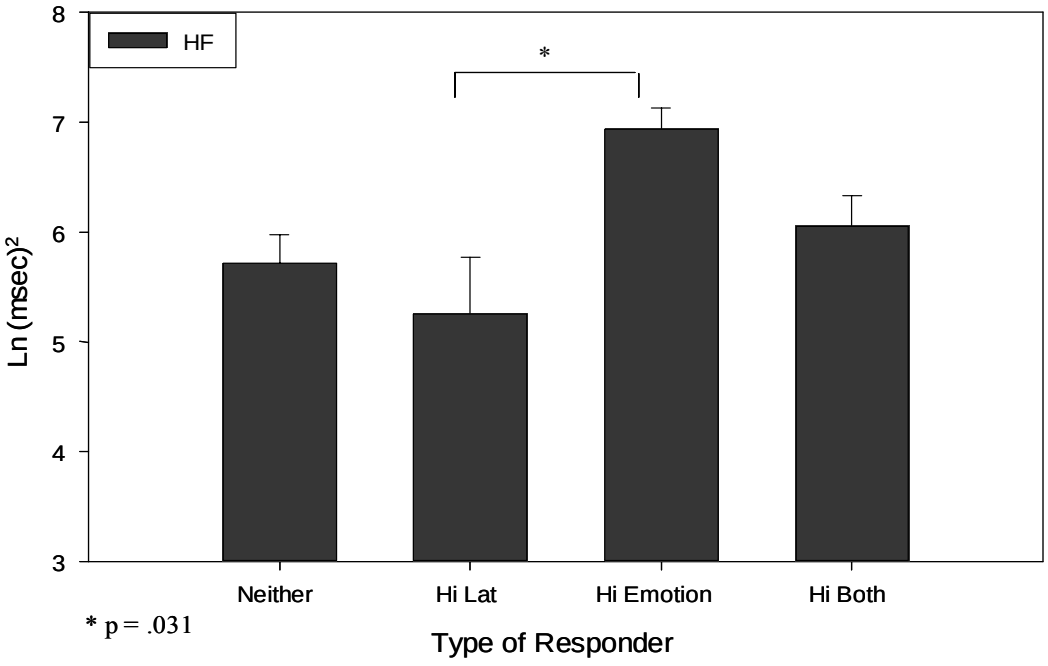


Figure 12: High vs. Low responders, LF component, Happiness Recall

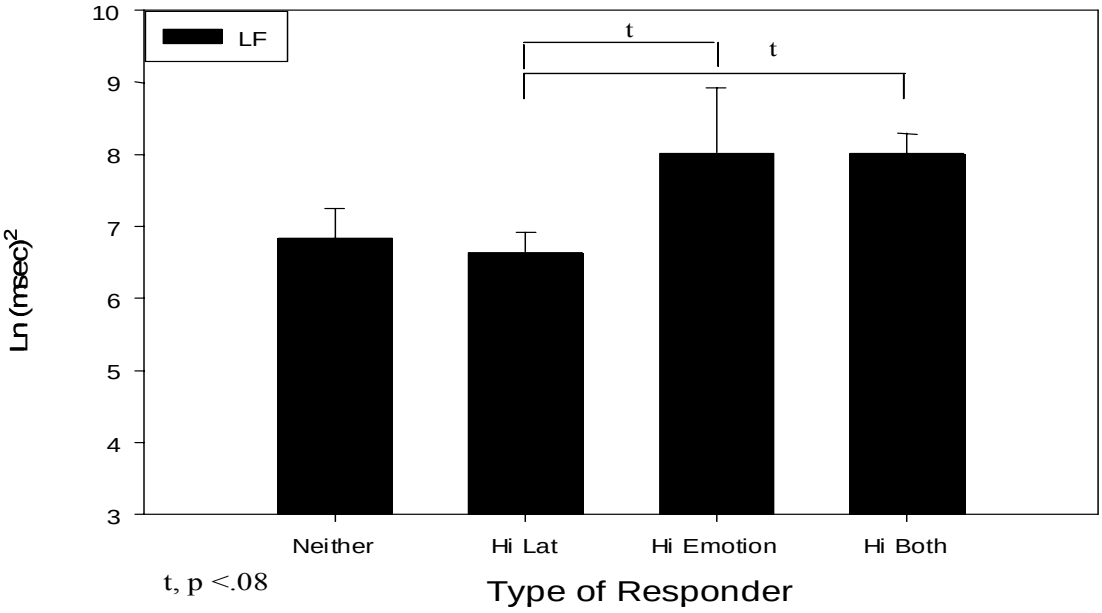
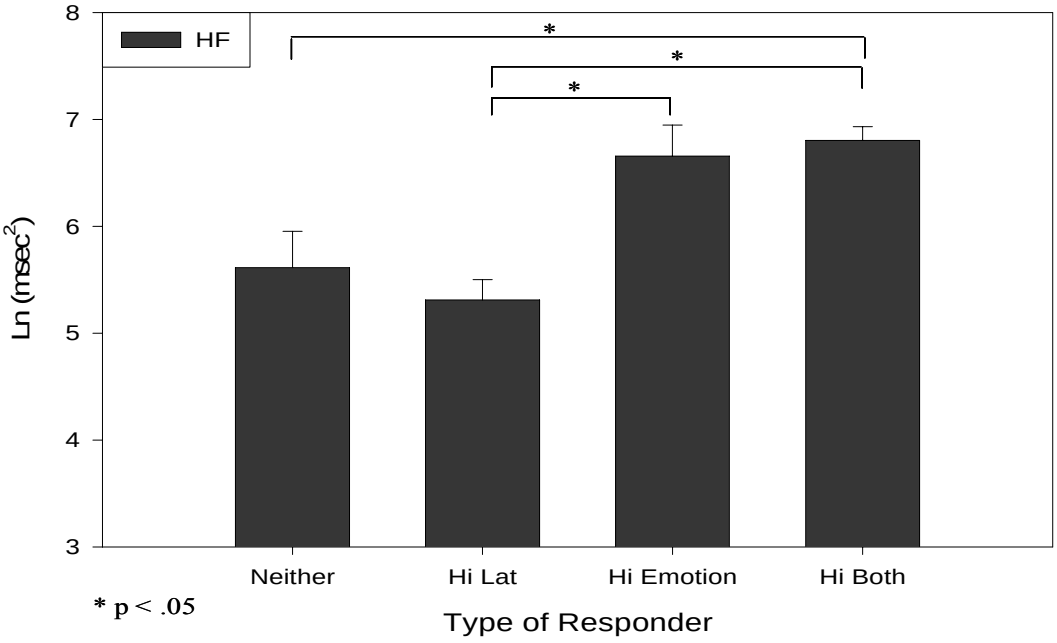


Figure 13: High vs. Low responders, HF component, Happiness Recall



Appendix A: IRB Approval Memorandum

UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
4301 JONES BRIDGE ROAD
BETHESDA, MARYLAND 20814-4712
www.usuhs.mil

July 13, 2005

MEMORANDUM FOR MS. MIRANDA NEWELL, DEPARTMENT OF MEDICAL AND CLINICAL PYSCHOLOGY

SUBJECT: Human Subjects Research Status of T072HJ

Protocol T072HJ, entitled "***The Connection Between Emotion, Brain Lateralization, and Heart Rate Varibility***," has been reviewed by the Uniformed Services University Office of Research and determined not to meet criteria defining human subjects research at 32 CFR 219.102. As such, this protocol does not require Institutional Review Board (IRB) review.

The purpose of this study is to use existing data to examine the relationship between positive and negative emotions, right and left brain lateralization, and heart rate variability (HRV). Data are obtained from Wijo Kop, Ph.D, USUHS. The IRB understands that you will have no relationship or interaction with the subjects from which data were obtained. The subject identity has been removed from the dataset and cannot be restored.

Should your project data sources or methodology change, please contact this office before you begin any new phase of your work so that we may review it with you. Otherwise we cannot ensure that you will be in compliance with all applicable human subject research regulations. The Office of Research IRB staff is a key resource that is available to assist you to ensure that you are in compliance with applicable human research regulations.

If you have questions regarding specific issues on your protocol, or questions of a more general nature concerning human participation in research, please contact me at 301-295-3303/9534 or rlevine@usuhs.mil.

Richard R. Levine, Ph.D.
Assistant Vice President for Research
and Executive Secretary, IRB

cc: Director, Research Administration
Chair, MPS
File

Learning to Care for Those in Harm's Way

Appendix B: Informed Consent Form

Subject Code:_____

CONSENT FORM

Title of Research: Biobehavioral Triggers of Cardiovascular and Cerebral Reactivity

Principal Investigator:	Nathan Fox, Ph.D.	(301) 405-2816
Co-Investigators:	Shari Waldstein, Ph.D.	(410) 455-2374
	Willem Kop, Ph.D.	(301) 295-3270
	David Krantz, Ph.D.	(301) 295-3270

SUBJECT'S NAME:_____ SOC. SEC. NO._____

Purpose of the Study: You are being asked to take part in a project that looks at your blood pressure, the electrical activity of your heart, and the electrical activity of your brain while you are resting and in response to positive and negative mental states, similar to those encountered in daily life, but enacted in a laboratory setting.

Procedures: As a participant, you will be asked to attend one, 2-1/2 hour experimental session at the Child Development laboratory (Institute for Child Study, Benjamin Building) on the University of Maryland at College Park campus. During this session, you will first be given a brief interview. If you meet the criteria for participating in our study on the basis of the interview, we will proceed with the application of our measurement instruments. First we will attach a set of 10 electrodes to your chest so that we can record the electrical activity of your heart (electrocardiogram; ECG). We will first clean those portions of skin on which the electrodes will be placed by rubbing the skin with alcohol. Next, we will place a blood pressure cuff on your left arm. The cuff will inflate and deflate periodically during the study in order to obtain blood pressure measurements. Finally, we will place a cap on your head which contains electrodes that will measure the electrical activity of your brain (electroencephalogram; EEG). There is no sensation involved in the measurement of your ECG or EEG.

During the laboratory session, you will be asked to engage in rest periods, and in several tasks consisting of viewing film clips, performing a computerized cognitive task, and description of recent experiences that you have encountered in you life. You will also be asked to complete short questionnaires about how you are feeling during the experiment.

Finally, you will be asked to complete a series of questionnaires that inquire about your thoughts, feelings and daily-life behaviors.

Risks/Discomforts: The risks involved to your health from participating in this study are minimal. All test procedures will be explained to you in detail by study staff before you participate in any aspect of the study. There is risk of minor discomfort associated with removal of the ECG electrodes from your chest. Additionally, some individuals experience mild discomfort while the blood pressure cuff is maximally inflated. However, duration of maximal inflation is only a matter of seconds.

Benefits: Your participation in this study will lead to an increased understanding of the cerebral and cardiovascular changes that occur in response to activities commonly encountered in daily life. This information will also assist in the ongoing study of stress and cardiovascular disease. Any clinical information about you that is detected through the tests in this program (such as high blood pressure) will be provided to you and, if you wish, to your physician.

Alternative to Participation: Your participation in this research project is voluntary. You are free to ask any questions that you might have, and you are free to withdraw from participation in this project at any time without penalty. Your withdrawal from this study will not affect any services you may receive from the University of Maryland at College Park. If you are a student at the University of Maryland at College Park your participation, non-participation, or withdrawal will not affect your academic/employment status in the University of Maryland system.

Costs/Compensation: All of the tests performed in this study are conducted at no charge to you. If something is found in testing that is of medical concern, we will explain it to you and your physician and advise you to seek additional medical consultation. Any expenses resulting from medical conditions found during testing will not be paid for by the investigators.

You will receive research credit for your course for your participation in this research project upon completion of all study procedures. In addition, you will receive $20 upon completion of all study procedures.

Confidentiality: The data obtained here will be held in strict confidence and will be used only for research purposes. Your name will never be given out with any of the results that may be published in a manuscript. To ensure that your confidentiality and anonymity is maintained during this study, your files will be identified by number. Information about your results will only be released with your signed consent. However, your research records, just like hospital records, may be subpoenaed by court order or may be inspected by federal regulatory authorities.

Thank you for participating.

1. I have freely volunteered to participate in this experiment.
2. I have been informed in advance as to what the procedures will entail.
3. I have been given the opportunity to ask questions, and have had my questions answered to satisfaction.

4. I am aware that I have the right to withdraw consent and discontinue participation at anytime without prejudice.

5. My signature below may be taken as affirmation of all of the above prior to my participation.

_____
Participant Signature

_____
Date

_____
Witness Signature

_____
Investigator Signature

Appendix C: Instructions to Participants

The purpose of this part of the study is to check your physiology when you feel happy, glad, or cheerful.

The way we have found it is best for most people to do this is to identify a recent incident in which you were really happy, glad, or cheerful. In fact, one that when you think about it, it still makes you happy. It may be for example a pleasant encounter with a good friend, or a special event that happened in your family. Choose any recent situation where you were really happy or glad.

Don't be embarrassed about how you felt or what happened, because the more realistic your feelings are, the more we will learn about your physiology. Sometimes, to relive a situation, it is good to take a moment to remember where you were, what the temperature was, and to close your eyes and almost see the situation.

Can you think of a situation like that?

(if not, prompt ..... did you have a nice time with someone else? ..... did you accomplish something that you are proud of?

WHO WERE YOU TOGETHER WITH?
(preferably, it is a specific situation with one other person)
WHEN DID THIS EVENT OCCUR?
(preferably less than 6 months ago)
WHERE DID THIS EVENT OCCUR?

TELL ME IN ONE SENTENCE WHAT LED UP TO THIS EVENT

TELL ME IN ONE SENTENCE THE PARTS THAT MADE UP THE EVENT ITSELF
(make sure the event has a clear beginning and end)

For the next 5 minutes, I would like you to recreate the incident as best you can. Starting with (beginning of event) and going to (end event). Tell me what you said and did, how the other person responded, what you were thinking and feeling, and what happened after that. (if subject does not volunteer, ask how he/she felt during at several points during the event).

I would like you to talk about the event during the first 3 minutes, and then, think about it during the next 2 minutes. While you are thinking about the happy event, we will cue you with cards in order to direct your attention. It is important for our measures that you do not talk during this second part.

Q-cards: visualize the situation
location
persons present
colors / illumination
your posture
concentrate on your feelings
were you smiling
temperature

expectations / wishes

After 30 seconds, I'll ask you to speak out loud what you would have liked to say in that situation, please prepare.

The purpose of this part of the study is to check your physiology when you get angry, irritated, or upset.

The way we have found it is best for most people to do this is to identify a recent incident in which you got really angry, frustrated, irritated, or upset. In fact, one that when you think about it, it still makes you upset. It may be for example an unpleasant encounter with a co-worker, or an argument that you had with someone in your family. Choose any recent situation where you were really irritated and upset with another person.

Don't be embarrassed about how you felt or what happened, because the more realistic your feelings are, the more we will learn about your physiology. Sometimes, to relive a situation, it is good to take a moment to remember where you were, what the temperature was, and to close your eyes and almost see the situation.

Can you think of a situation like that?

(if not, prompt ..... never been really upset with your partner? ..... anybody especially rude to you?

WHO DID YOU GET ANGRY WITH?
(make sure subject got angry at only one person)
WHEN DID THIS INCIDENT OCCUR?
(preferably less than 6 months ago)
WHERE DID THIS INCIDENT OCCUR?

TELL ME IN ONE SENTENCE WHAT LED UP TO THIS INCIDENT

TELL ME IN ONE SENTENCE THE EVENTS THAT MADE UP THE INCIDENT ITSELF
(make sure the INCIDENT has a clear beginning and end)

For the next 5 minutes, I would like you to recreate the incident as best you can. Starting with (beginning of event) and going to (end event). Tell me what you said and did, how the other person responded, what you were thinking and feeling, and what happened after that. (if subject does not volunteer, ask how he/she felt at several points during the event).

I would like you to talk about the incident during the first 3 minutes, and then, continue to think about it during the next 2 minutes. While you are thinking about the annoying event, we will cue you with cards in order to direct your attention. It is important for our measures that you do not talk during this second part.

Q-cards: visualize the situation
location
person involved
colors / illumination
your posture
concentrate on your feelings
were you shouting
temperature
fantasies / wishes

After 30 seconds, I'll ask you to speak out as loud as you can whatever you would have wanted to that person, prepare now, shout at the beep.

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